California Master Gardener Handbook

Second Edition

Dennis R. Pittenger
Editor

University *of* California
Agriculture and Natural Resources

Publication 3382

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Contents

Preface and Acknowledgments

The *California Master Gardener Handbook* was conceived in the mid 1980s, shortly after I began my career with the University of California Cooperative Extension (UCCE) as the statewide urban horticulture specialist. A comprehensive resource manual on horticulture and related topics was sorely needed for training and supporting UC Master Gardeners because, at that time, each local Master Gardener program prepared its own unique collection of training and support materials using existing UCCE leaflets, fact sheets, and local CE publications. Many of these publications were intended for production agriculture or professional horticulture audiences rather than home gardeners, and the collections were inconsistent from program to program. With the publication of the first edition of this handbook in 2002, UCCE had its first compilation of fundamental horticultural reference materials designed primarily for master gardeners statewide to use as a tool during and after completing a local master gardener training program. Because of its usefulness, the handbook has also proven to be a valuable general reference for other serious home gardeners and many professional horticulturists. This second edition continues to stand as the principal UC reference on basic horticulture for master gardeners and related users of the book, containing detailed information, important facts, and concepts not found in other texts written for these audiences.

As was true for the first edition, the content of the second edition has been developed assuming no prior knowledge of the topics on the part of the reader and from the perspective that readers seek science-based information they can use to sustainably maintain their landscapes and gardens while becoming effective problem solvers. Chapters are designed as stand-alone units providing in-depth information, and they reflect the unique writing styles of their authors. Thus, while there is some necessary repetition of key concepts and noticeable differences in form and approach among the chapters, all information is objective and research based.

The second edition of the *California Master Gardener Handbook* includes updates of technical information in each chapter, some reorganization of information presented, and new content on important emerging topics. Chapters 2 through 9 include important background information on subjects related to general care and management of horticultural crops. Chapters 10 through 18 address the specific culture of numerous horticultural crops important to home horticulturists in California. Chapters 19 through 21 provide information on landscape and garden design, poisonous garden plants, and how to develop plant problem-solving skills. New information on invasive plants has been added in chapter 8, and principles of designing and maintaining landscapes for fire protection has been added in

chapter 12. In addition, chapters 4 ("Water Management"), 9 ("Controlling Garden Pests Safely"), 11 ("Lawns"), 19 ("Landscape and Garden Design"), and 20 ("Poisonous Plants") have been extensively revised to reflect timely information not previously available. Household and structural pest content has been eliminated since it is no longer featured in master gardener training programs. Nutritional data for individual crops has also been omitted from this edition, as has the appended background information on how nutritional data is derived and interpreted. Information on the nutritional value of many vegetables and fruits can be found on the US Food and Drug Administration website, www.fda.gov.

The bibliographies of most chapters contain references to UC publications and other external resources that serve as the basis for some of the content. Users of the handbook may want to consult these resources to gain additional information on particular topics. Additional information on UC publications can be found at the UC Division of Agriculture and Natural Resources Communications Services website, anrcatalog.ucdavis.edu. Up-to-date pest-related information can be found at the UC Statewide Integrated Pest Management Project website, www.ipm.ucdavis.edu, while a variety of helpful and timely gardening information can be found at the UC California Garden Web website, cagardenweb.ucdavis.edu.

Useful conversions for many units of measure found in the handbook or needed in caring for gardens and landscapes are located at the back of the book. A glossary of important technical terms used in the book is provided, and the entire book is extensively indexed.

The first edition of the handbook was the culmination of planning, teamwork, and determined effort among numerous UC academic colleagues dedicated to the mission and goals of the master gardener program. This second edition represents their commitment to assuring that the book continues to provide the program with the highest quality, up-to-date technical support feasible. The chapter authors and contributors to the book are urban horticulture subject-matter experts, and many are long-time supporters of master gardener training. Several of them have retired, and others are likely do so in the near future. I sincerely thank all the individuals who served as authors and contributors for this book, and I dedicate this second edition to the authors who have retired.

I have personally observed the commitment of certified UCCE master gardener volunteers to disseminate the information learned in their training program, as well as the desire for other serious gardeners and horticulture professionals to enrich their horticultural knowledge. I hope that this second edition of the *California Master Gardener Handbook* continues to be a valuable, practical, and respected reference for them.

Authors

The following colleagues revised or developed new versions of chapters for the second edition of the California Master Gardener Handbook, and their dedication to improving and updating its content deserves acknowledgment.

JUDITH A. ALSOP, Director, Sacramento Division California Poison Control System (retired); Clinical Professor of Medicine, VCF, UC Davis School of Medicine; and Health Sciences Clinical Professor, UC San Francisco School of Pharmacy

BERTHOLD O. BERGH, Specialist Emeritus, Botany and Plant Sciences Department, UC Riverside

MARK BOLDA, County Director and Farm Advisor, Strawberries and Caneberries, UCCE Santa Cruz County

Lawrence Clement, County Director and Farm Advisor Emeritus, UCCE Solano and Yolo Counties
Akif Eskalen, Extension Subtropical Plant Pathologist, Plant Pathology Department, UC Riverside
Ben Faber, Soils and Water Farm Advisor, UCCE Ventura and Santa Barbara Counties
Delbert S. Farnham, County Director and Farm Advisor (retired), UCCE Amador County
Nancy Garrison, Horticultural Advisor Emeritus, UCCE Santa Clara County
Ralph C. Gay, Farm Advisor and 4-H Youth Development Advisor (retired), UCCE Yolo County
Pamela M. Geisel, Director Emeritus, UCCE Statewide Master Gardener Program
Deborah D. Giraud, Plant Science Farm Advisor, UCCE Humboldt and Del Norte Counties
M. Ali Harivandi, Turfgrass, Soil, and Water Farm Advisor Emeritus, UCCE Alameda, Santa Clara and Contra Costa Counties
Janet Hartin, Environmental Horticulture Farm Advisor, UCCE San Bernardino, Los Angeles, and Riverside Counties
Donald R. Hodel, Environmental Horticulture Farm Advisor, UCCE Los Angeles County
John F. Karlik, Environmental Horticulture Farm Advisor, UCCE Kern County
Demetrios G. Kontaxis, Farm Advisor (retired), UCCE Contra Costa County
Carol Lovatt, Professor, Plant Physiology, Botany and Plant Sciences Department, UC Riverside
Donald J. Merhaut, Extension Nursery and Floriculture Crops Specialist, Botany and Plant Sciences Department, UC Riverside
Richard H. Molinar, Farm Advisor Emeritus, UCCE Fresno County
Julie P. Newman, Environmental Horticulture Farm Advisor Emeritus, UCCE Ventura and Santa Barbara Counties
Mikeal Roose, Professor of Genetics, Botany, and Plant Sciences Department, UC Riverside
Deborah Silva, Freelance Technical Editor and Writer
Georgios Vidalakis, Extension Specialist and Plant Pathologist and Director of the Citrus Clonal Protection Program, Department of Plant Pathology, UC Riverside
Paul M. Vossen, Tree Fruits and Nuts Farm Advisor, UCCE Sonoma and Marin Counties
James Walworth, Professor and Extension Specialist, Soil, Water, and Environmental Science Department, University of Arizona

Collaborators

In addition to chapter authors, the following individuals provided background information, guidance, or technical review during the revision of chapters in this edition of the handbook.

A. James Downer, Environmental Horticulture Farm Advisor, UCCE Ventura County
Mary Louise Flint, Associate Director, Urban and Community IPM, UC Statewide IPM Program, and Extension Entomologist, Entomology and Nematology Department, UC Davis (retired)
Victor Gibeault, Extension Environmental Horticulturist Emeritus, Botany and Plant Sciences Department, UC Riverside
Janet S. Hartin, Environmental Horticulture Farm Advisor, UCCE Los Angeles and San Bernardino Counties
Tracy L. Kahn, Principal Museum Scientist and Curator, Citrus Variety Collection, Botany and Plant Sciences Department, UC Riverside
Chris Karlik, B.S.L.A., designer and architectural illustrator, Minneapolis, MN.
Lorence R. Oki, Extension Landscape Horticulture Specialist, Plant Sciences Department, UC Davis
Timothy E. Williams, Staff Research Associate Emeritus, Botany and Plant Sciences Department, UC Riverside

Peer Reviewers

UCCE employs a rigorous anonymous peer review process in which academic associate editors in specific disciplines ensure technical quality standards in the production of its publications. The *California Master Gardener Handbook* is one of the largest and most comprehensive statewide publications to undergo this scrutiny. It was an enormous and complex process for a book of this scope, managed by ANR Associate Editors Mary Louise Flint, Janet S. Hartin, Anthony O'Geen, and Lorence R. Oki. We thank the peer reviewers for their contribution to this book.

Special Acknowledgments

I thank Deborah Silva for her dedicated service as technical editor and co-author of several chapters in of the first edition of this book, which served as the basis for much of the contents of this second edition.

I also thank the team members of the publication production unit within Communication Services of the UC Division of Agriculture and Natural Resources who were responsible for the final editing, design, and publication of the book:

Ann Senuta, who coordinated production and printing.
Stephen W. Barnett, who edited the manuscripts and managed the production of the book.
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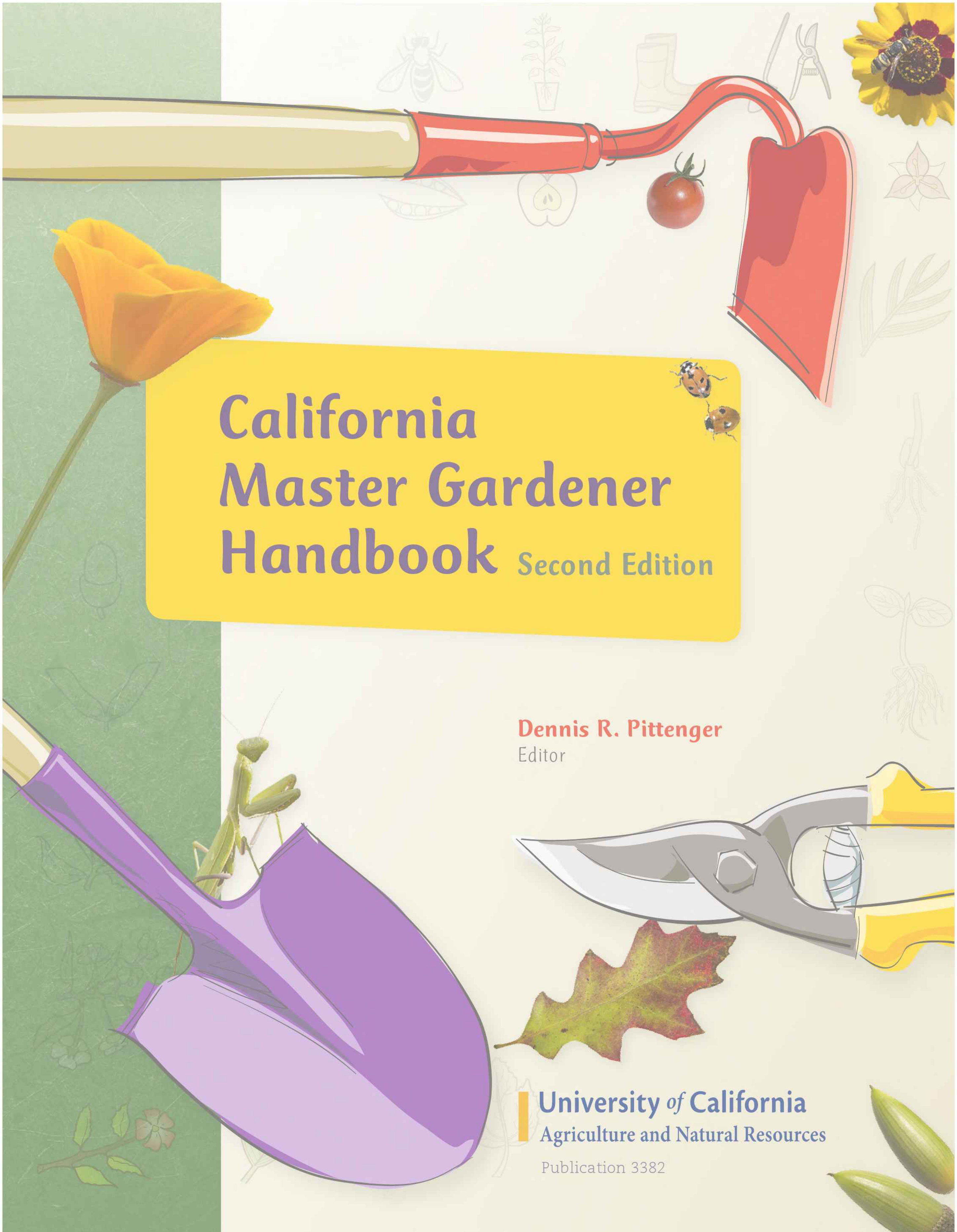
Evett Kilmartin, who assembled and prepared photographs and figures.
Hazel White, who proofread and indexed the final copy.

Dennis R. Pittenger
Editor
Area Environmental Horticulture Advisor
UCCE Los Angeles County / Botany and Plant Sciences Department, UC Riverside



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Overview of the University of California Master Gardener Program

1

Pamela M. Geisel and Dennis R. Pittenger

Overview of the University of California Master Gardener Program

The University of California Master Gardener Program has been in existence since 1980, when UC Cooperative Extension in Sacramento and Riverside Counties offered the first training. In 1981, both Sonoma and Fresno Counties began their programs and from there launched a program with a rich history of accomplishments that has made the program a vital and thriving part of the University of California Division of Agriculture and Natural Resources. Since that time, the UC Master Gardener Program has grown to serve 50 counties in California through the efforts of over 6,000 certified volunteers.

The UC Master Gardener Program is one of many master gardener programs throughout the United States and Canada. Since 1972, when the first master gardener program started in Washington State, the program has spread to more than 45 states and four Canadian provinces and claims more than 94,000 volunteers who share the information they learn with the gardening public in exchange for master gardener training by local university experts.

The UC Master Gardener Program

The UC Master Gardener Program is an effective partnership between the University of California, county governments, and motivated citizens. Certified UC master gardeners represent UC Cooperative Extension and are considered "agents" of the University. They broaden UC's ability to attain a greater sphere of influence through contact with more than 2 million people each year in addition to a wide range of print, television, radio, and electronic media outreach efforts. From the program's inception in 1980 through 2014, UC master gardeners donated over 4,286,366 volunteer hours of educational outreach to the public.

Certified UC master gardeners are extensively trained volunteer horticulturists who make up an important aspect of UC Cooperative Extension across most of the state (fig. 1.1). They provide research-based information on sustainable urban horticulture practices in their communities. They staff booths at county fairs and local farmers' markets, host plant clinics at libraries and community centers, and appear on radio and television. They conduct workshops on sustainable landscape and gardening practices that include topics such as home food production, safe pest management, water conservation, and composting. They develop and maintain demonstration gardens to share timely, research-based information on plant science and technology. Master gardeners operate help lines in county offices, answering thousands of telephone and e-mail inquiries from the gardening public. Some also conduct applied research projects addressing local gardening problems. While UC master gardeners work primarily with adults, they

also extend their efforts into schools by facilitating school gardens, often in collaboration with other UC programs such as 4-H and Youth Development or the federally funded Expanded Food and Nutrition Education Program (EFNEP). These collaborations provide training for teachers, staff, and parents on vegetable gardening practices that they can apply in school garden programs. UC master gardeners also help train community gardeners on effective horticultural practices.

Figure 1.1

California counties with active UC Master Gardener Programs (shaded).

Mission and Goals

The purpose of the UC Master Gardener Program is to extend to the public research-based information verified by UC experts about home horticulture, pest management, and sustainable landscape practices. In partial exchange for training and materials received from UC and external experts, UC master gardeners provide volunteer services in their communities.

The UC Master Gardener Program has the following goals and impacts for California and its citizens.

Healthier Plants

Increase understanding of the interactions between people and plants.

Encourage appropriate selection, placement, and care of plants.

Teach integrated pest management practices.

Healthier Environment

Promote optimal water use.

Improve soil quality.

Reduce reliance on pesticides.

Reduce the volume of green waste in landfills.

Healthier Gardeners

Consume more vegetables and fruits.

Enjoy gardening.

Learn new skills.

Increase the number of gardens in the community.

Obtain better health through gardening.

Healthier Communities

Introduce more people to gardening.

Encourage group involvement.

Improve communications skills.

Improve cultural understanding.

Program Administration

The UC Master Gardener Program is overseen by a statewide director who helps to establish programmatic mission and direction, develops core policies to guide the program, and facilitates programmatic training and organization. Each county-based program is administered locally by a paid staff member or by the volunteers themselves with oversight by a UC Cooperative Extension advisor who is an academic member of UC ANR.

Training

The University of California takes master gardener training and volunteer certification very seriously. Each county or regional group has the flexibility of tailoring their specific UC master gardener training to meet local needs, provided that it meets the required core training standards. Each master gardener receives from 40 to 50 hours of extensive instruction in topics such as

introduction to horticulture

soil, fertilizers, and irrigation

plant diseases

entomology and insect pests

home vegetable production

weed science

integrated pest management (IPM)

fruit and landscape trees

lawn management

diagnosing plant problems

vertebrate pest management

Presenters are experts in their respective fields and provide timely, objective, research-based information that includes sustainable practices. Classes typically meet 1 day per week for 2 to 4 hours over 15 to 18 weeks and include lecture, demonstration, and practical field experiences. Some classes are taught online using video conferencing or through online teaching modules. Instructors in the program include UC Cooperative Extension advisors and specialists, professors who are faculty on UC campuses and members of the University's Agricultural Experiment Station, and other experts from industry and local colleges and universities.

People from all walks of life become UC master gardeners: business people and professionals, educators, public employees, retired persons, homemakers, and students are typical participants. No degree is required for program eligibility. Adults of all ages, ethnicities, and backgrounds with varying levels of prior experiences in home gardening and pest management are accepted into the program. A strong desire to serve the community is an important attribute.

After completing the training program and passing the written examination, UC master gardener graduates are required to volunteer a minimum of 50 hours in the local community within their first year. UC master gardeners choosing to recertify donate 25 volunteer hours in successive years and must also complete 12 hours of continuing education annually, much of which is provided by UC and local experts and by attending regional, statewide, or international master gardener conferences.

The Many Philosophies of Home Gardening

Home gardeners are faced with a multitude of choices regarding gardening products and philosophies. The UC Master Gardener Program provides objective, scientifically valid information that allows volunteers to lead home gardeners to informed choices. UC master gardeners provide a range of research-based options rather than promote any one horticultural practice. Master gardeners respect individual beliefs, but they provide only information that has a scientific basis, including pest or disease control recommendations. For pest and disease control advice, master gardeners use only UC publications and recommendations that have been reviewed for accuracy by the UC Statewide Pesticide Coordinator. Examples of information sources used by UC master gardeners to address home horticulture inquiries include UC publications available through the UC ANR publication website, anrcatalog.ucdavis.edu/, and the UC IPM website, ipm.ucdavis.edu/. Whenever feasible, UC master gardeners focus on practices that have been documented as being environmentally sustainable.

UC master gardeners work with gardeners who have many different viewpoints. For perspective, general approaches and methods of some of the more popular gardening philosophies are provided below. These approaches center on various techniques of managing and improving soil structure and health; in some instances, there are local, national, and international organizations that provide additional information.

Organic Gardening and Growing

In the 1940s, Sir Albert Howard, a British agronomist, first popularized organic gardening and farming. He worked in rural India, where farmers had to recycle natural nutrients from waste products because they could not afford to buy off-farm inputs. Sir Albert was disturbed by the newly emerging petroleum-based fertilizer products because he thought the natural cycles of building soil health were being ignored. He encouraged farmers to return wastes to the soil, avoid petrochemicals in combating insects, and avoid synthetic fertilizers. J. I. Rodale continued Sir Albert's work through the Rodale Institute, which today is a major publisher of organic gardening information.

Organic gardeners and growers generally use only naturally derived materials and no synthetic substances. Because soil health is stressed, organic growers compost and add organic matter to the soil to improve tilth and to keep plants fit to fight pests and disease. To combat pests, botanical insecticides, soaps, and other largely nontoxic controls are used, and cultural controls, such as cultivation and mulching, are used to fight weeds. Resistant varieties, pheromone confusion, and beneficial insects are newer technologies employed by organic growers.

In commercial agriculture, *organic* has a legal definition. Farmers must comply with regulations to become certified organic producers so they can label and sell their products as Organic. In California, the agricultural commissioner's office of each county registers organic growers and provides lists of materials they are allowed to use in their operations. Nationally, the U.S. Department of Agriculture (USDA) manages the National Organic Program, which develops, implements, and administers production, handling, and labeling standards for organic agricultural and horticultural commodities.

Biodynamic Gardening

Biodynamic gardening was developed from the writings of Austrian philosopher Rudolph Steiner. Soil fertility is maximized through environmentally balanced gardening. Raised beds, double digging, and compost additions are used. Double digging prepares the soil two spades (about 24 in) deep. Organic materials are dug into the lower level, then the top 12 inches are prepared for planting. A loose, well-drained soil is created in the beds.

Biodynamic gardening uses two basic preparations that are purported to be soil enhancers. The first preparation is made by filling cows' horns with manure and burying them at certain times in winter according to the moon's cycles. The resulting composted organic matter is dissolved in water and applied to the soil. This preparation is said to contain life forces that make the soil very fertile and conducive to plant growth. The other preparation, a white powder made in summer by mixing flowers together, is used as a pest and disease control and is believed to be an anti–life force substance.

Biodynamic–French Intensive Gardening

Biodynamic methods were synthesized with older French intensive gardening methods by Alan Chadwick in the 1960s to form the biodynamic–French intensive method that he employed in developing a large-scale garden at the University of California, Santa Cruz. Most recently, John Jeavons refined this method.

Permaculture

Permaculture is a land-use philosophy that includes community planning and development in designing human settlements and agricultural systems that imitate natural ecological relationships. Not being limited to a specific method of production, it typically includes perennial crops along with crop rotation using cover crops, hedgerows, and aquaponics. Gardening and recycling methods include edible landscaping, companion planting, trellising, spiral herb gardens, and vermicomposting. Other technologies advocated by permaculturists are solar and wind power, energy-efficient housing, and solar cooking.

Square Foot Gardening

This is a method of planting into large raised boxes that are filled with mixtures of compost, peat, or vermiculite. The boxes measure 4 feet by 4 feet, allowing ready access from all sides, so it is not necessary to walk on the media, avoiding compaction. Plants are set out on a grid pattern in a spacing that matches the size of the harvested plant. Planting is scheduled to produce a steady stream of vegetables, herbs, and flowers rather than producing a single crop. When the first square foot plot is empty, something else can be sown immediately. There is no spacing between rows, so even a small plot can produce a relatively large amount of produce. Because plants are being put out and replaced on a regular basis, there is less opportunity for weeds to establish and grow. The beds can be made as high or low as is needed for people with different physical limitations.

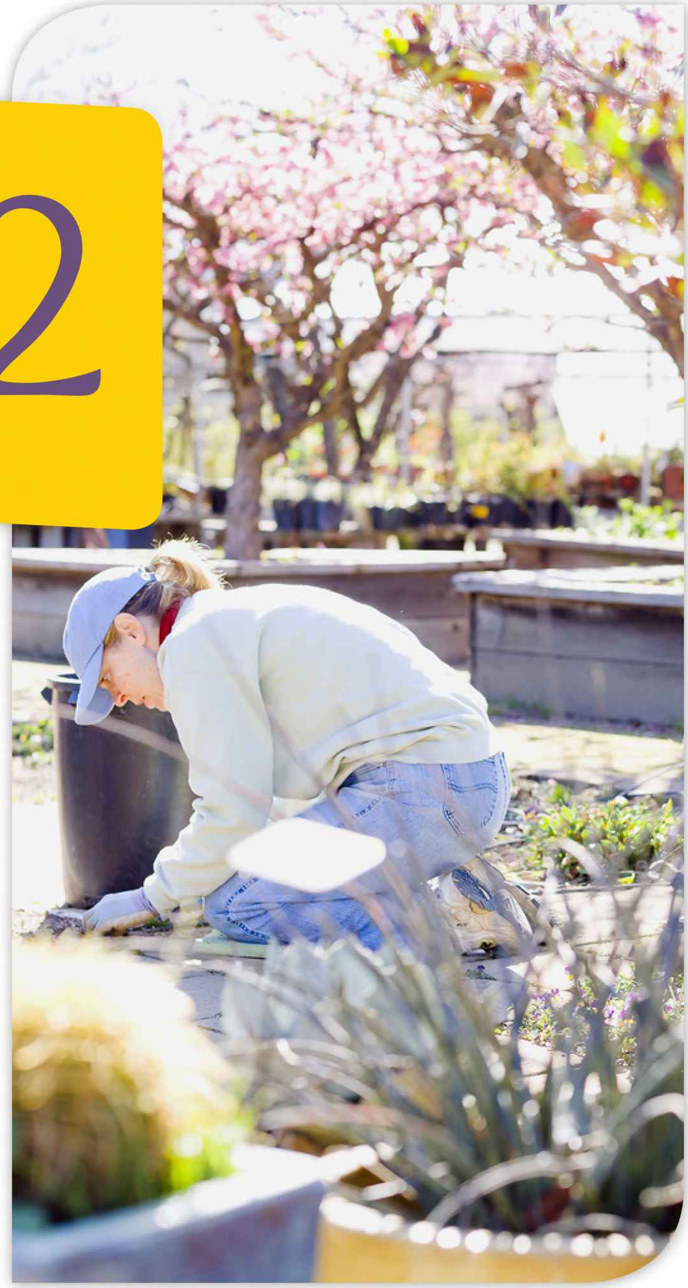
Sustainable Practices

Many Californians are expressing renewed interest in approaches to designing and maintaining their gardens and landscapes that are environmentally sound—also known as green or sustainable gardening and landscaping. In addition, new state and local ordinances and mandates require increased water conservation and energy efficiency that affect the design and management of landscapes and gardens. The many definitions of sustainable landscaping and gardening center on design and maintenance practices that reduce demand for all types of resource inputs, make use of renewable resources, and protect environmental quality. The general philosophy of sustainability is to use resources at the rate and quantity they are generated and to ensure that the ecological functions of a site are not adversely affected so that plantings can be maintained in perpetuity. On a practical level, the goal is for landscapes and gardens to be resource efficient and require reduced amounts of water, fertilizer, pesticides, labor, and energy so that they perform their intended functions indefinitely with minimal negative impact on the environment.

It is sometimes asked why the UC Master Gardener Program does not have an explicit focus on sustainable gardening. As noted earlier, master gardeners are expected to disseminate scientifically defensible information approved by the University of California. Key principles of sustainability—reduce, reuse, recycle—are routinely built into UC recommendations that can be readily applied to gardens and landscapes of all types and sizes. Sustainable principles have been the focus of UC education and research programs through the years, although terminology has evolved and changed. Recommended practices that promote sustainability also promote the growth and maintenance of healthy plants, such as proper plant selection based on climate and microclimate, supplying the right amount of water and nutrition in a timely way, and implementing effective integrated pest management strategies. These practices reduce the water, pesticide, and fertilizer inputs needed to establish and maintain landscapes and gardens, and they are an integral part of information provided in this book.

Introduction to Horticulture 2

Dennis R. Pittenger



Learning Objectives

Learn principal characteristics of green plants, plant structure, and common horticultural terminology.

Understand general vegetative and reproductive growth processes of plants and the factors that influence them.

Learn classic applications of fundamental horticultural knowledge.

Introduction to Horticulture

Horticulture is usually described as both an art and a science. Understanding fundamental principles of plant physiology and botany, combined with skill and intuition in employing them, ensures the maximum use and enjoyment of plants.

Botany is the study of plants and includes all facets of their structure and physiology. Horticulture is an applied science that uses basic scientific principles, largely from botany, to develop and implement practical technologies. The current classification of agricultural crops into the specialties of horticulture and agronomy can be traced back to medieval times, when land was divided into large districts called manors. Extensive field plantings of grains and forages were possible under the manor system, giving rise to the discipline of agronomy.

Horticulture originates from the medieval practice of growing intensively managed kitchen gardens that provided fruits, vegetables, herbs, and ornamental plant materials for the lord's manor. The English word *horticulture* is derived from the Latin words *hortus* (garden) and *colere* (to cultivate). Today, horticulture embraces the intensive culture of fruits, vegetables, ornamentals, herbs, and other high-value, often perishable, specialty crops. In contrast, agronomy includes crops such as corn, wheat, rice, alfalfa, and other grains and forages that are usually grown on a large scale with less-intensive management.

The size, productivity, and other quantitative characters of a given plant are determined by the interaction of its genetic potential (traits) with the environment. The range of expression for any trait is set by the plant's genetic blueprint, whereas the specific expression within the range depends on the environment. For example, a given tomato variety may be genetically able to produce up to 25 pounds of fruit, but it will produce only 10 pounds when inadequately watered. Horticulturists employ scientific methods to investigate and understand plant responses to various environmental conditions, then develop and employ technologies to manipulate the environment and production system to yield predictable plant responses. Such intensive management is often required to produce horticultural commodities. Intensive management is economically feasible because the produce grown commands premium prices or has high intrinsic value to consumers and home gardeners.

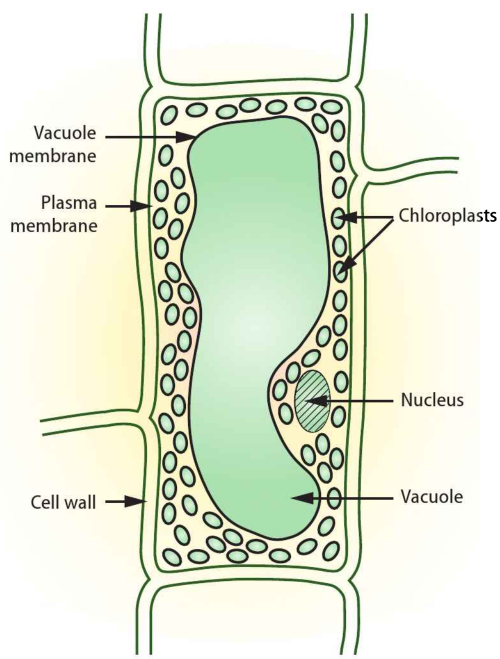


Figure 2.1

Simplified plant cell showing the nucleus, chloroplasts (plastids that contain chlorophyll), and vacuole. Plant cells are bounded by a membrane and cell wall. Most of the cell volume is occupied by the vacuole in this plant cell. The contents of a cell are collectively known as protoplasm.

What Plants Are

Plants are complex living organisms without consciousness or mobility. Green plants are essentially living factories that produce their own food and serve directly or indirectly as the source of food and support for nearly all other living organisms. Like animals, they are composed of microscopic cells, three-dimensional block-like structural units. Unlike animals, however, green plants

produce their own food via photosynthesis, regenerate certain lost or damaged organs and tissues, and possess rigid cell walls made mostly of cellulose. The cell wall functions as a protective barrier around the cell and strengthens its integrity.

All essential life processes occur within cells or groups of cells. A simplified plant cell is shown in figure 2.1. The entire content of cells, known as protoplasm, is composed of 85 to 90% water (by weight), 1 to 3% minerals dissolved in the cell sap, and 10 to 15% assorted organic compounds and substances. Water serves as the solvent in sap that transports dissolved minerals from the soil and sugars from the leaves to all cells in the plant. It also serves as an essential component in many plant processes, maintains cell turgor (rigidity), and indirectly regulates growth. Thus, water typically constitutes 85% or more of the weight of a plant.

Pectin serves as a cementing agent between cells. Immediately inside the cell wall lies a selectively permeable membrane that helps regulate inflow and outflow of materials and compounds. Within the cell, most of the liquid substances (cell sap) are found in the vacuole, a large cavity.

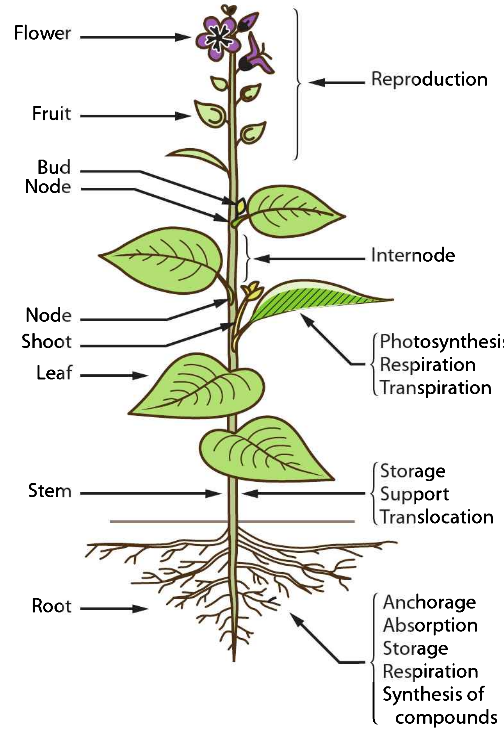
The nucleus and plastids are important solid structures in a cell. The control center of the cell, the nucleus, contains the genetic code information (DNA) that controls the physiological functions of cells and the overall features of the whole plant (DNA is identical from cell to cell). Plastids are specialized bodies within plant cells; plastids called chloroplasts contain the green pigment chlorophyll and are significant because they conduct photosynthesis.

Plant Structure

Although plant cells are independent units, the sophisticated organization and specialization of cells make up the whole plant and carry out essential life processes (fig. 2.2). Masses of similar kinds of cells form tissues, and groups of tissues may form organs. Many horticultural crops are

Figure 2.2

Important structures and functions of a seed plant.



prized for their production of unique modifications of certain tissues or organs (fig. 2.3).

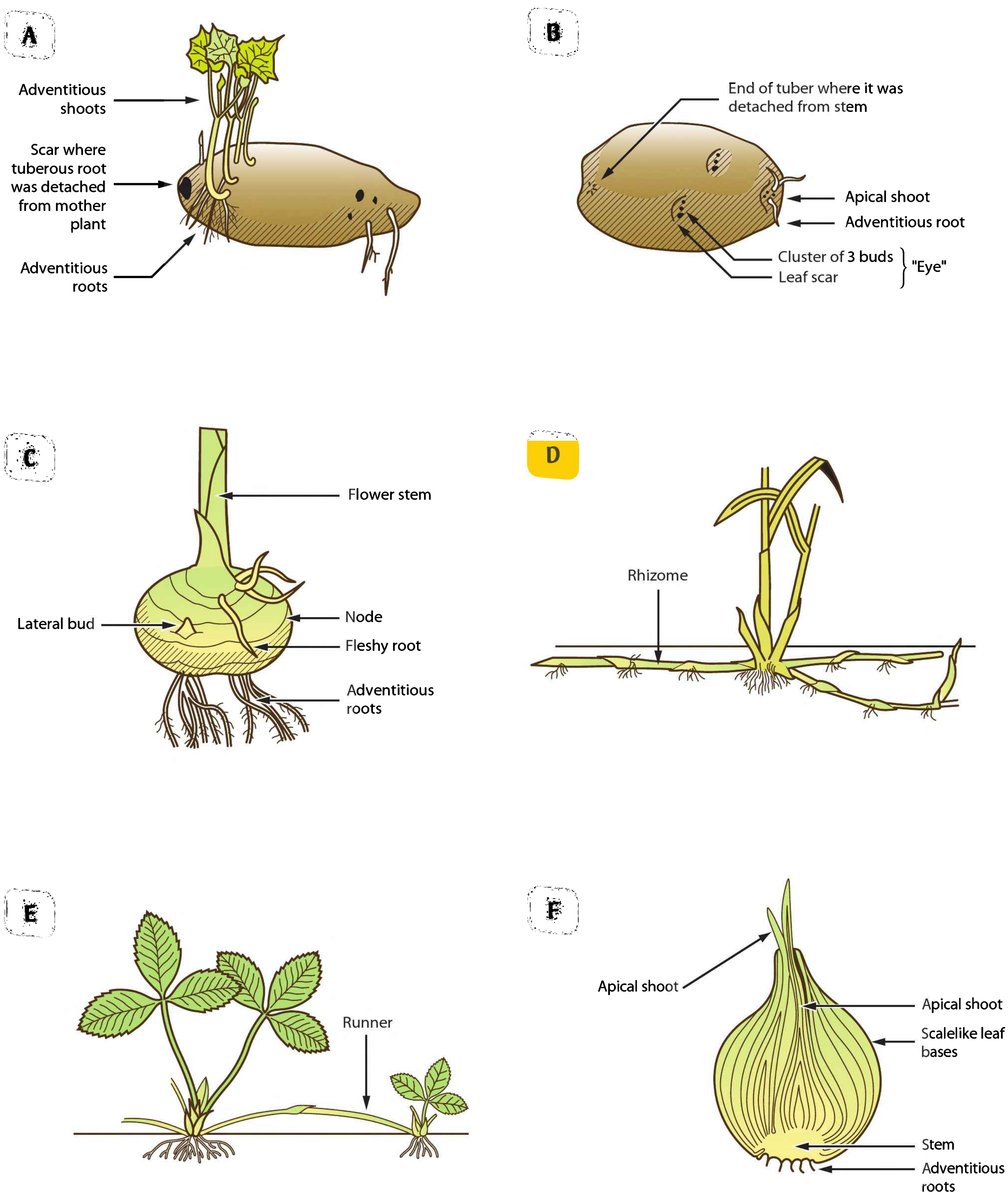
Meristems

Meristems are plant tissues in which cells divide to reproduce, grow, and develop new tissue. The most common meristems are apical (terminal) and lateral. Found in shoot tips, root tips, and buds, apical meristems are responsible for the increase in the length of these plant parts (fig. 2.4; see also fig. 2.6). The increase in stem and root diameter, or thickness, is due to the growth of a lateral meristem called the cambium (see fig. 2.6). In many grasses, the meristem responsible for shoot growth is found near the base of the plant; this is why mowing turfgrass at the proper height does not injure or remove the growing point of the plants.

Meristematic areas, which are normally just a few cells deep, may produce shoots (vegetative growth) or flowers (reproductive growth), depending on when and where the meristem is active. All active

Figure 2.3

Modified structures of selected horticultural plants. (A) Tuberous root (sweet potato; modified root). (B) Tuber (Irish, or white, potato; modified stem). (C) Corm (gladiolus; modified stem). (D) Rhizome (bermudagrass; modified stem). (E) Runner, or stolon (strawberry; modified stem). (F) Bulb (onion; modified stem and leaves).



meristems receive priority for the food materials and minerals available within the plant. For this reason, they are often referred to as sinks.

Figure 2.4

Apical meristems of shoots and roots. The shoot apical meristem (left) and root apical meristem (right) are involved in the formation of new cells via cell division and in plant growth via cell enlargement. Note that the root apical meristem is not at the very tip of the root but instead is protected by the root cap.

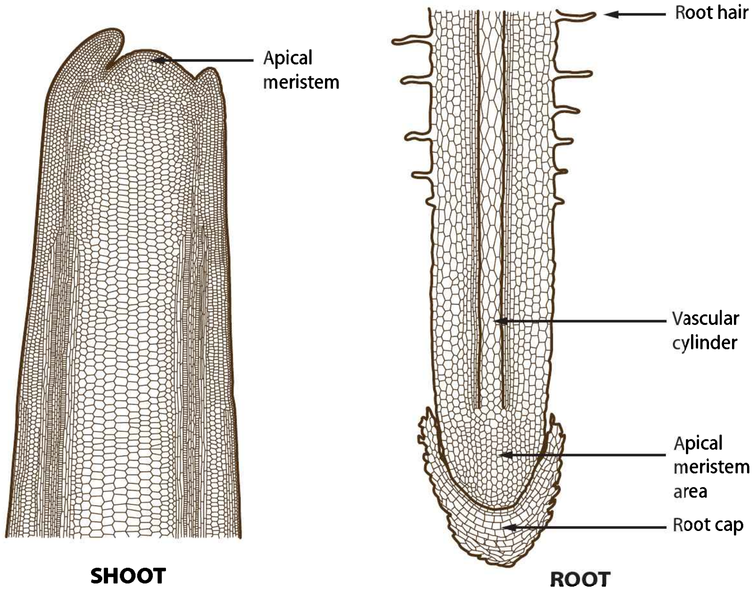
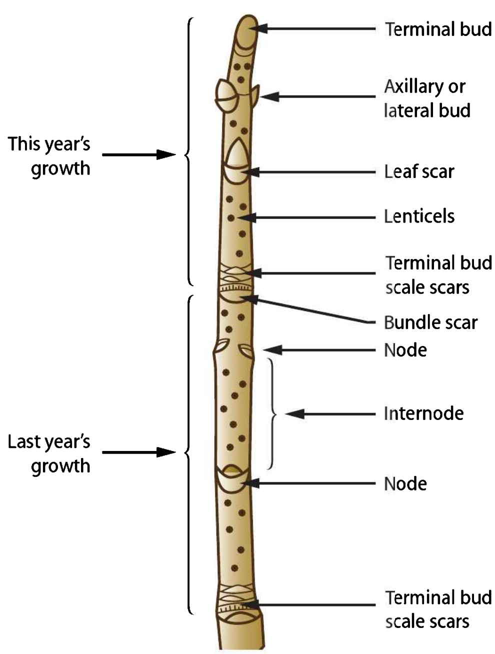


Figure 2.5

Structures of a woody twig (stem) with opposite bud and leaf arrangement. Annual growth is measured by the distance between terminal bud scale scars and the current terminal bud.



Roots

The primary functions of roots are to take up water and soluble mineral nutrients from the soil, produce essential compounds, store excess food materials, and anchor the plant (see fig. 2.2). Roots require water and oxygen from the soil and food materials produced in the shoots in order to function and grow properly. Examples of horticultural crops grown for their edible roots include carrots and sweet potatoes.

Structurally, roots may be woody or nonwoody. Cambial (meristematic) tissue in roots causes them to increase in diameter over time, particularly in perennial and woody plants. Most of the water and nutrient uptake occurs in small, fibrous, nonwoody roots and root tips.

The root tip is the meristematic area responsible for increasing root length. Frequently, root hairs are present just behind the root tip. These hairs serve to increase the surface area of the root system and allow it to take up water and minerals more efficiently. Particularly in woody plants, a large main root, the taproot, develops with a small number of smaller structural or fibrous roots growing from it, whereas other plants form only a dense network of fine, fibrous roots. Plants grown from cuttings and plants grown in containers seldom develop a taproot system. Taproots diminish in size as the plant matures.

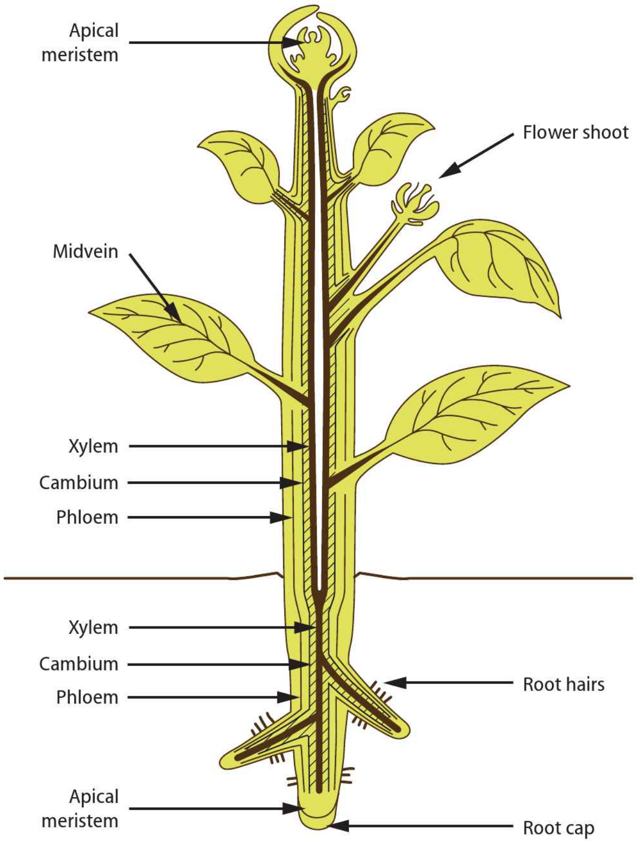
Some plant parts, such as leaves and stems, can regenerate roots after roots are removed from the plant. Roots arising from some plant part other than roots are known as adventitious roots (see fig. 2.3).

Stems and Shoots

Stems and shoots are often the most prominent aboveground portion of a plant (see fig. 2.2). Shoots are tissue made up of either developing stems and leaves (leafy shoots) or stems and flowers (flowering shoots). Shoots support food-producing foliage, store food materials, and contain tissues that conduct water and photosynthetically produced food materials

Figure 2.6

Vascular tissues are continuous from the root tips to the shoot tips. They are organized differently in monocots and dicots.



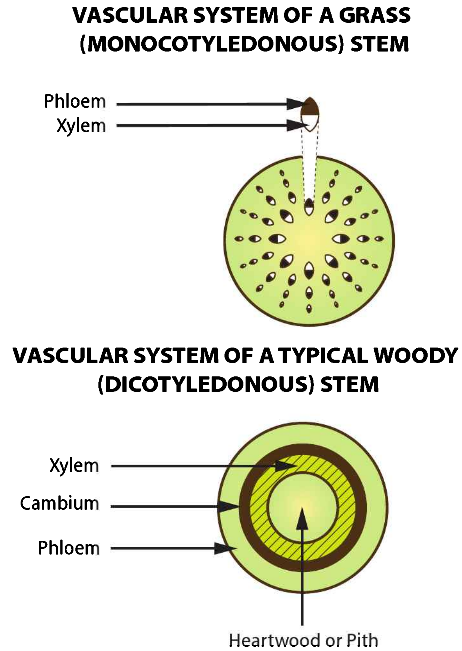
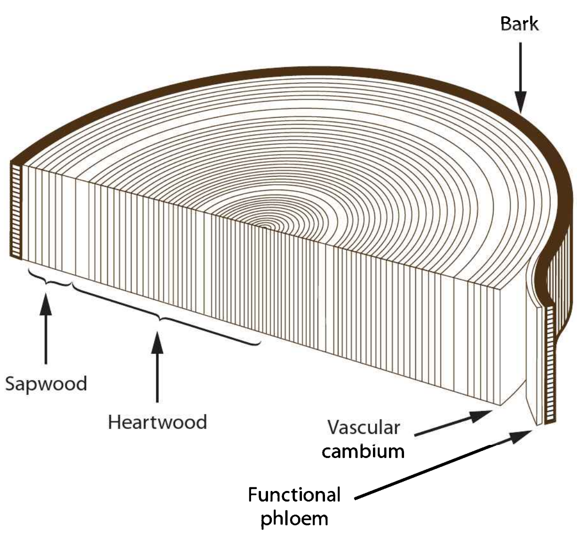


Figure 2.7

Cross section of a hardwood dicot tree trunk. Vascular tissues (phloem and xylem) are concentrically arranged. The functional phloem is a narrow layer of cells immediately underneath the bark. Cambial tissue separates the phloem from the xylem. Sapwood is the active portion of the xylem; heartwood is the inactive xylem that makes up most of the wood in large stems and trees.



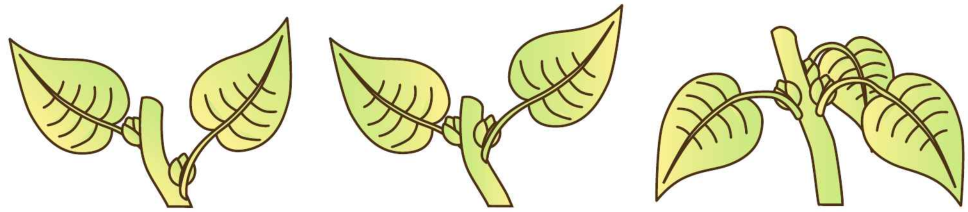
throughout the plant. Unique features of stems are that they contain buds and nodes. Nodes are portions of a stem, often enlarged in diameter, from which leaves or buds grow; the portion of stem between two nodes is an internode (fig. 2.5).

Phloem is tissue that conducts photosynthetically produced food and other compounds from the leaves to other plant parts. Materials can move up or down in the phloem. Water and dissolved mineral nutrients from the soil are conducted from the roots upward to all the aboveground parts via the xylem. Together, phloem and xylem are known as vascular tissue and usually form a continuous, multibranched system from every root tip to every shoot and leaf tip (fig. 2.6).

The cambium is responsible for the increased diameter growth of stems and roots and is usually associated with the vascular tissue. In typical woody stems, the xylem and phloem occur as concentric zones separated by the cambium, which is a few cells wide. Plants in the grass family, however, have xylem and phloem occurring together in numerous vascular bundles scattered throughout the stem;

Figure 2.8

Common arrangements of buds and resulting shoots around a stem.



cambial tissue is normally absent in these bundles. The two types of xylem in woody plants are active xylem, or sapwood, and inactive xylem, or heartwood (fig. 2.7). Although the sapwood is usually not very thick, the heartwood is the wood that makes up the trunk and the center portion of large tree limbs. Inactive xylem cannot transport water and minerals, but it does provide structural integrity and a food storage area for the plant. The inactivity of the heartwood explains why hollow trees can often remain alive: the active xylem, cambium, and phloem exist in the very outer perimeter of the trunk.

Nonwoody (herbaceous) plants and stems have a thin outer protective tissue, or epidermis. In herbaceous plants, the water-filled cells provide adequate strength to support the plant, much like the stiffening of a garden hose under pressure. Because this mechanism is insufficient to support larger plants, a stiffening process called secondary growth occurs, giving rise to woody plants. Secondary growth in stems is usually associated with the presence of cambial tissue. Woody stems, such as those in trees and shrubs, may develop a thick or tough protective exterior tissue, or bark (see fig. 2.7). In woody plants, specialized tissues (fibers) begin to form as the stem elongates, and the stem becomes more or less rigid a short distance below the apical meristem. Because the stem cannot elongate below the apical meristem, it is limited to increases in diameter. Thus, the length of the nodes (the distance between leaves and branches) remains constant for the life of the plant.

Stems may be greatly modified from the classic form, and many horticultural crops are grown for their unique stems. Aboveground stem modifications consist of crowns, runners, stolons, and spurs; belowground modifications include bulbs, corms, tubers, and rhizomes (see fig. 2.3).

Buds

Buds are meristematic structures along the stem that are composed of compressed immature leafy shoots, flowers, or both. They may be dormant for a portion of the year or for many years before they become active.

Buds are named according to position (see fig. 2.5). Those found at the tips of shoots are terminal, or apical, buds, and those found along the sides of stems are lateral buds. Lateral buds that occur in the area where the leaf attaches to the stem (the leaf axil) are axillary buds.

The arrangement of buds and resulting shoots around a stem occurs in a particular pattern for each plant species. These patterns, along with bud appearance, are particularly useful when identifying a plant. The most common arrangement patterns are alternate, opposite, and whorled. In the alternate arrangement, single buds occur in one plane but alternate from one side to the other in a zigzag fashion. Buds in an opposite arrangement occur in pairs, with one bud on each side of a plane simultaneously. A whorled arrangement occurs when three or more buds occur in different planes at one point on a stem or when single buds occur in three or more planes along a stem (fig. 2.8).

Certain horticultural crops have specialized buds (see fig. 2.3). For example, the “eyes” of white (Irish) potato tubers are actually leaf scars or nodes in which three buds occur; the center buds normally break dormancy and produce new leafy

shoots. Brussels sprouts are large vegetative lateral buds occurring on the main stem of the plant.

Leaves

Leaves provide the surface area a plant needs to collect sunlight and conduct photosynthesis, which produces food for the plant. A simple leaf and its components are shown in figure 2.9. Note the distinct blade and petiole. A bud is present and can be seen at the point where the petiole attaches to the stem. Horticultural plants possess leaves that vary greatly in appearance, structure, and function. Blades vary widely and may be simple (not divided) or compound (divided into smaller segments, or leaflets; see fig. 2.10). In compound leaves, buds are not present where the leaflets attach to the petiole. Compound leaves may be palmate (hand-like in form) or pinnate (with segments arranged like a feather). The margins of leaf blades also vary in pattern among species. The axil is the area above the point where a leaf attaches to the stem.

Leaf veins are the continuation and termination of xylem and phloem from the roots and stems. The midvein (or midrib) is the most prominent. Three patterns of venation (palmate, pinnate, and parallel) commonly occur in plants (fig. 2.11).

Leaves have an epidermis, a thin protective layer of cells, on their upper and lower surfaces (fig. 2.12). Some species have a waxy or varnish-like coating (cuticle) that provides additional protection and reduces water loss. The epidermis and cuticle thicken as the leaf matures. The thickness of the epidermis and cuticle depends on the amount of light the leaf receives. A plant in a shady location has a thinner cuticle and epidermis than the same plant in full sun.

Immediately under the upper epidermis are densely packed cells that contain chlorophyll, the green pigment necessary in photosynthesis. Inside the lower epidermis are widely spaced cells that also have chlorophyll. The open spaces between these cells permit free movement of water vapor, carbon dioxide, and oxygen in and out of the leaves through tiny openings called stomata (see fig. 2.12). Pairs of specialized cells (guard cells) control the opening and closing of each stomate. Guard cells respond to light so that sto-

Figure 2.9

The parts of a simple leaf are shown in relation to typical stem and bud structures.

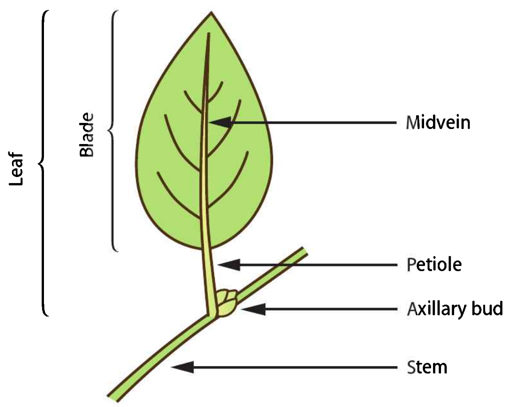


Figure 2.10

Compound leaves are composed of multiple petiole and blade segments referred to as leaflets. Note the absence of any buds where leaflets attach to the petiole.

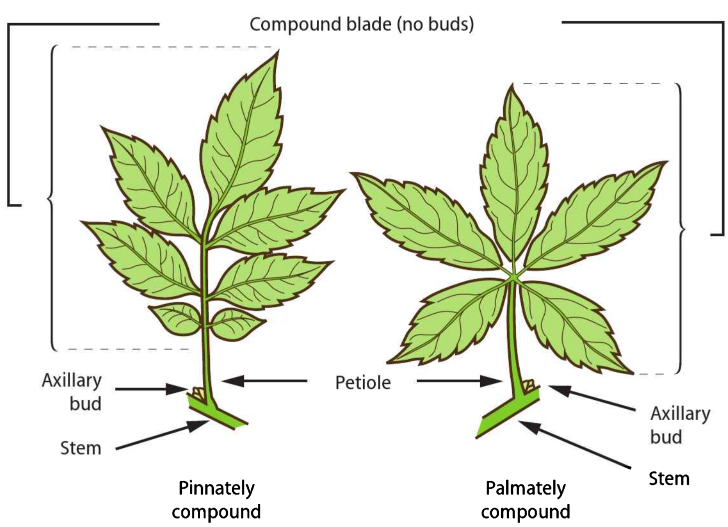
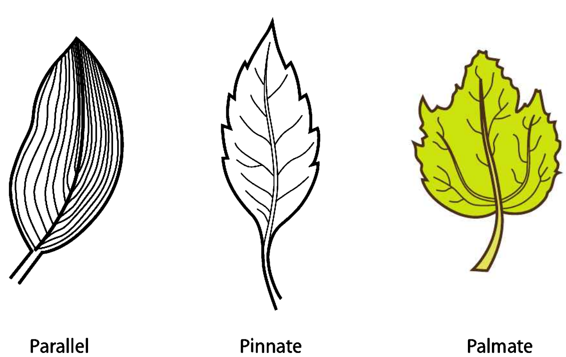


Figure 2.11

Leaf venation patterns.



mata are normally open in daylight and closed in the dark. The number and size of stomata vary widely among species. Among tree species, for example, the number varies from approximately 100 stomata per square millimeter to 600 stomata per square millimeter of leaf surface. Stomata are usually found in higher numbers on the lower leaf surface.

Figure 2.12

Internal structure of a leaf in cross section.

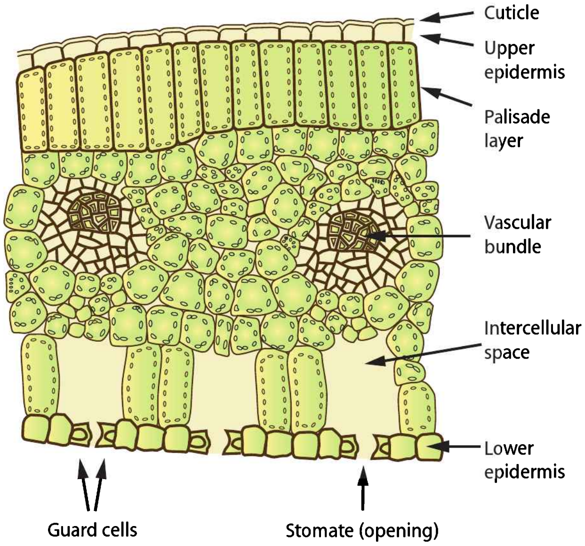
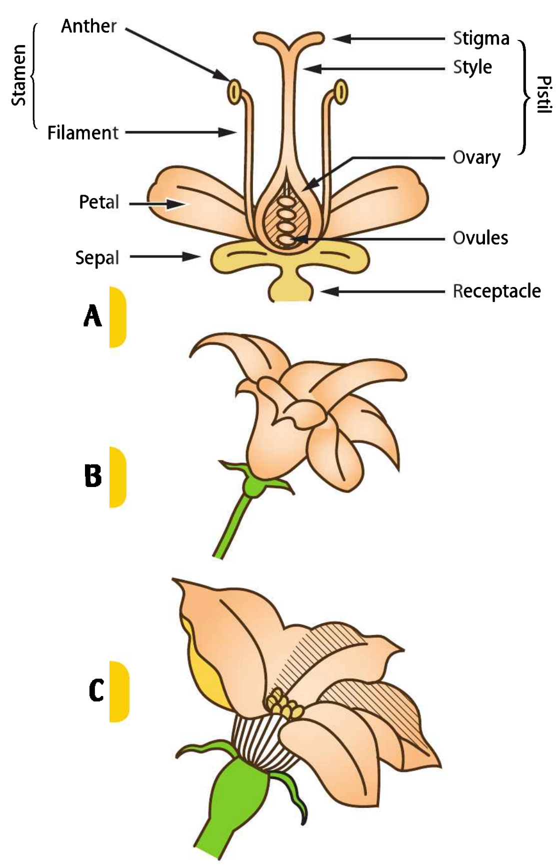


Figure 2.13

Complete, male, and female flowers. (A) Generic complete (perfect) flower in vertical section. (B) Male squash flower. (C) Female squash flower.



Flowers

Flowers contain the male or female (or both) sexual structures of plants and are therefore the organs where sexual reproduction occurs. Depending on the species, flowers may contain both male and female structures (perfect, or complete, flowers), or they may have only male or only female structures (imperfect, or incomplete, flowers) (fig. 2.13).The principal male structure is the stamen, and the principal female structure is the pistil. Incomplete flowers that have only male structures are called staminate, whereas incomplete flowers that have only female structures are pistillate. Plants with both staminate and pistillate flowers at different locations on the same individual plant (e.g., corn, squash, pumpkins, melons, begonias, oaks, some maples, some ashes, and birches) are monoecious. Species in which staminate and pistillate flowers occur on separate individual plants (e.g., asparagus, date palm, kiwifruit, holly, poplars, spinach, and willow) are dioecious.

Within the stamen, the anther holds the pollen grains, and in the pistil, the ovary contains the ovules. When pollination and fertilization occur (see the section “Reproductive Development,” below), the ovary and sometimes the receptacle swell to form a fruit, and one or more ovules develop into seed. Petals are normally the most conspicuous part of a flower, although some plants (e.g., poinsettia, anthurium, sunflower, and broccoli) are known and grown for their other flower parts. Sepals are the small, green, leaflike structures found at the base of flowers (see fig. 2.13) and are the “caps” on tomatoes and strawberries. The receptacle is the plant part where the floral structures are attached; in some species, such as apple, it becomes integrated into the fruit as it develops.

Figure 2.14

Typical seed structures illustrated in a garden bean seed.

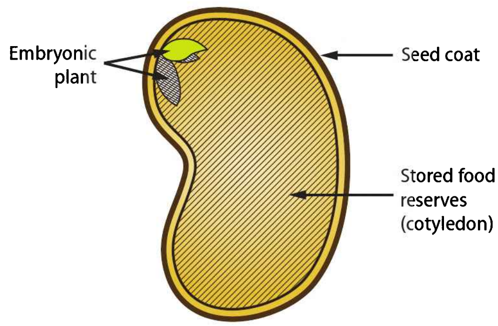
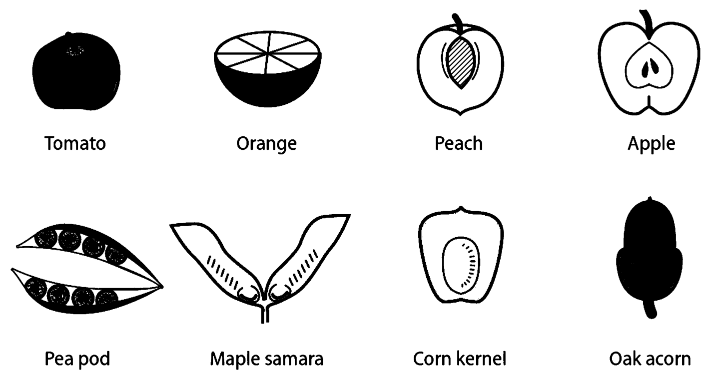


Figure 2.15

Simple fruits.



Seeds

In most species, the seed is the product of sexual reproduction. The seed is important because it contains an embryonic plant in a dormant state of development along with food reserves to sustain it through germination (fig. 2.14). The food reserves may be carbohydrates, fats, oils, or proteins. A protective covering, the seed coat, is also found on most seeds.

Fruits

Botanically speaking, a fruit is the plant part that contains the mature, swollen ovary and the seed; familiar examples include oranges, apples, and tomatoes (fig. 2.15). In some species, other flower parts may be included as part of the fruit (e.g., the receptacle in apples). Numerous horticultural plants are grown specifically for their delicious or aesthetic fruit. Some fruits are commonly (and erroneously) called vegetables because they are consumed as vegetables at meals and because nutritionists speak of them as vegetables. Botanically speaking, however, squashes (zucchini, pumpkins, acorns, etc.), green beans, cucumbers, tomatoes, and eggplants are fruits, as are apples, pears, plums, strawberries, oranges, and lemons.

As with meristems, fruits are referred to as sinks because they receive priority for food materials within the plants.

Classification of Plants

In order to study and fully understand plants, it is necessary to record and communicate information about them in a structured, orderly fashion. Grouping and classifying plants according to their use or readily observed characteristics provides methods for achieving this. Although various terms are employed in systems that classify and characterize plants, the most common classification systems are growth habit, structure or form, leaf retention, climatic adaptation, use, and botanical or scientific classification.

Growth Habit

Plants can usually be classed as annuals, perennials, or biennials. Annuals complete a life cycle from seed to flowering to reseeding in 1 year or one growing season, then die. Perennials continue growing for several years. A perennial may go through repeated annual flowering and seed-producing cycles before it dies, or it may grow for several years before it performs a single seed-productng cycle then dies. Agave species are classic examples of the latter, whereas common woody landscape plants are examples of the former. Horticulturists often use the term *perennial* to describe the diverse assortment of ornamental plants that are nonwoody but continue to live from year to year. The aboveground parts of perennials such as daffodils, yarrow, and foxglove die back and regrow each year.

Biennials require 2 years or two growing seasons to complete their life cycle. Plants grow leaves and shoots the first year, then flower the second year. These plants typically require a cold dormant period after the first year in order to develop flowers the second year. Cabbage is an example of a biennial plant.

A crop may be an annual under certain environmental conditions and a perennial under other conditions. Tomatoes, for example, are usually considered annual plants, but they may live more than one season in areas where freezing temperatures are infrequent.

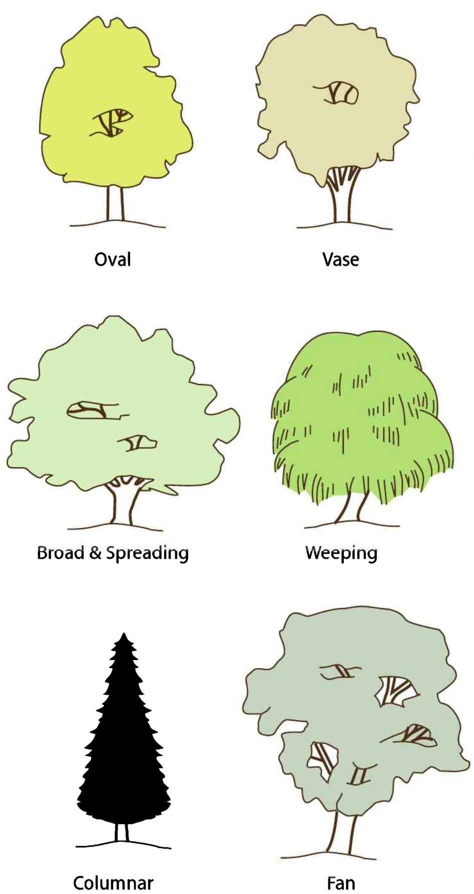
Structure or Form

The basic structure, size, and form of plants can be used to group or classify them in very broad terms. Plants that have hard, fibrous stems are woody, whereas those that do not are herbaceous. Tender-stemmed species in general are sometimes called herbs.

When woody plants are grouped according to their form, they are often called vines, shrubs, and trees. Vines trail along the ground unless offered some type of support. Short, upright-growing plants with several main stems are considered to be shrubs, and tall ones with a single or a few main stems are usually considered to be trees. Trees may be further defined according to the general shape that their canopies naturally develop; a number of terms are used to describe them (fig. 2.16).

Figure 2.16

Forms and shapes of trees.



Leaf Retention

Perennial plant species generally fall into one of two categories: deciduous or evergreen. Deciduous plants lose all their leaves for some period in the fall and winter months. Evergreen plants do not lose all their leaves at once, although they do cast off old leaves on a periodic basis. At any one time, however, an evergreen plant always has some green leaves. Evergreens are further divided into broadleaf (e.g., azalea, some magnolias) and needle leaved (e.g., pine, redwood).

Climatic Adaptation

Perennial plants are classified according to the minimum temperatures they normally tolerate. Tropical plants are injured severely or killed when temperatures remain near freezing (32°F). Subtropical plants tolerate short exposures to temperatures at or slightly below freezing and usually tolerate overnight temperatures around freezing. In contrast, temperate plants are well adapted to prolonged subfreezing temperatures that occur in cold-winter climates and can endure temperatures considerably below freezing.

Most annual vegetables, flowers, and turfgrasses are classified in a similar fashion. Those that tolerate some amount of short-term freezing are known as cool-season or hardy crops, whereas those that are killed, dormant, or injured by freezing temperatures are warm-season or tender crops. Cool-season crops grow best and

produce the highest-quality produce during seasons that feature average daytime temperatures from 55° to 75°F, and warm-season crops grow and develop best when average daytime temperatures are from 65° to 95°F.

Use

Plants are often categorized by their use or the part of the plant consumed. When a plant is cultivated primarily for its aesthetic beauty or environmental enhancement qualities, it is considered an ornamental. Horticultural plants grown principally for some edible organ(s) are called fruits, nuts, herbs, or vegetables. Although botanically, a fruit is the plant structure that contains the seed, from a use standpoint, a fruit is any plant part consumed for its dessert qualities; parts consumed during the main portion of a meal are considered herbs or vegetables. For example, tomatoes contain seed and are technically fruit, but they are consumed in salads and other main course dishes (and rarely in desserts) and are therefore considered vegetables.

Botanical, or Scientific, Classification

The most precise and least confusing method of classifying or categorizing plants is the internationally recognized botanical, or scientific, binomial classification system, which provides specific, positive identification for thousands of plants worldwide. Using this system eliminates the confusion arising from multiple common names for the same plant. The common name of a given plant can vary from one locality or country to another, but its scientific name is consistent from one location to another over time.

The scientific binomial name of a plant consists of two parts—the genus followed by the specific epithet, sometimes informally called the species—that are Latinized words or taken directly from Latin. Together, the two words name a species. For example, *Rubus idaeus* is the scientific name of the species red raspberry; *Rubus* is the genus and *idaeus* is the specific epithet, a species within the genus. Latin is the primary language used for these terms because it was the scholarly language in use when the scientific classification system was developed. Scientific names are italicized or underlined. Genus names are nouns with the first letter always capitalized, whereas the specific epithets are usually adjectives and are always lowercase.

The scientific system is based on the principle that plants can be grouped according to similarities in morphological structures and genetics that are a result of their common ancestral history. As an analogy, the generic name of a plant is somewhat like the last name of a person. Thus, the last name Smith is analogous to the genus *Quercus* (oak). The specific epithet of a particular oak species is analogous to the first name of an individual within the Smith clan.

All plants within a genus are closely related and possess similar morphological characteristics. Similarities of flowers and fruits are the most widely used criteria in classification. Species within a genus vary according to slight differences in these common morphological characters. The genetic makeup of individual plants in a species is very similar, so individuals may be identical in appearance. Plants in the same species (and often those in the same genus) can be grafted to one another. Moreover, plants in a species (and among species within a genus) are often sexually compatible. There are, however, a number of exceptions to this general rule among horticultural commodities.

A great deal of confusion surrounds the term *variety* because it is used in two different ways. In scientific classification, a variety is a subclassification of a species in which plants growing in the wild developed and possess some minor but important morphological trait that is readily heritable. However, *variety* can also refer to a subclassification of a species that was developed and retains desirable

characteristics through human propagation and cultivation; but this is properly called a cultivar (cultivated variety). For example, the three botanical varieties of the pea plant are

Pisum sativum var. *sativum*: common English pea
Pisum sativum var. *arvense*: field pea
Pisum sativum var. *saccharatum*: sugar pea

Each botanical variety of the pea has a unique morphological characteristic that developed naturally. When pea seeds are sold, however, only cultivated variety (cultivar) names are used, such as Progress #9 or Little Marvel, to identify the horticultural variety of pea.

In another example, the tomato is scientifically known as *Lycopersicon esculentum*, but a number of tomato cultivars are not botanical varieties, based on their unique fruit or plant characteristics (e.g., Celebrity, Big Boy). Many other examples come from fruit, vegetable, and ornamental species.

The convention for writing a species and its cultivar is demonstrated as follows: *Liquidambar styraciflua* 'Palo Alto' or *Liquidambar styraciflua* cv. Palo Alto, which is the Palo Alto cultivar of the sweet gum tree species. It has unique, consistent fall color and growth habit and is maintained through budding or grafting.

The term *clone* is related to variety and cultivar. A clone is a group of genetically identical plants originating from a single individual and reproduced by vegetative means such as cuttings and grafts. A clone is a specific type of cultivar, but a cultivar is not necessarily a clone, because cultivars may be propagated by sexual (seed) or asexual means.

A hybrid is the progeny of a cross between two individuals with one or more different genes. In horticulture, a hybrid is usually the offspring produced by seed resulting from a controlled cross between two different plants within a specific epithet. These offspring can become a cultivar if they possess one or more desirable traits and continue to be produced by repeating the hybrid cross. Many vegetable crops and bedding plants are hybrid cultivars. Botanical hybrids, on the other hand, are technically designated with the symbol ×. Use of the symbol indicates a plant is the result of a hybrid of two unique plants within a genus when it is placed between the genus and specific epithet, as in *Magnolia* × *soulangiana*, which is a cross of *Magnolia heptapeta* and *Magnolia quinquepeta*. The name of a plant that is a hybrid derived from plants in two different genera is written with the symbol preceding the name, as in × *Mahoberberis aquisargentii,* which is a cross between *Mahonia aquifolium* and *Berberis candidula*.

A basic understanding of the plant classification system is helpful, as it enables horticulturists to identify or predict problems and similarities among related plants. Historically, there were two biological kingdoms. Plants were classified in the kingdom Plantae, whereas the other kingdom, Animalia, comprised animals. Over the past three decades, the biological classification system has been significantly revised in response to advances in the sciences of genomics and molecular biology (fig. 2.17). Revelations from these disciplines continue to produce new views about biological relationships and the diversity of living organisms in our world. Although there is no consensus, biologists now commonly classify organisms among six kingdoms under three domains that are essentially superkingdoms. Plant taxonomists are currently debating possible changes in the membership of organisms in the kingdom Plantae.

The scientific subgroups of the kingdom Plantae also undergo periodic reorganization and renaming as biologists learn more about fundamental relationships among groups of plant species. Of the ten divisions (phyla) currently accepted within the plant kingdom, seven include plants with vascular systems (xylem and phloem), roots, stems, and leaves. Most of the horticulturally important plants belong to five of these divisions among two groups of seed-bearing plants: those

Figure 2.17

Hierarchy of biological classification. Species are classified into groups in progressively broader categories, culminating in the domain.
An example is shown for the Golden Delicious variety (cultivar) of apple, *Malus domestica* 'Golden Delicious'.

Domain: Eukarya

Kingdom: Plantae

Phylum (plural = Phyla): Anthophyta

Class: Dicotyledon (Eudicotyledon)

Order: Rosales

Family: Rosaceae

Genus (plural = Genera): *Malus*

Specific epithet and cultivar: *Malus domestica* 'Golden Delicious'

whose seeds lie exposed at the base of scales, usually in a cone (gymnosperms), and those that are true flowering plants (angiosperms). The gymnosperms include conifers (pines, firs, spruces, and redwoods), cycads, and ginkgo, while the angiosperms comprise most of the plants familiar to gardeners, including all the flowering plants whose seed are enclosed in a dry or fleshy fruit that develops from the ovary within the flower. Ferns, mosses, and horsetails belong to other divisions within the plant kingdom.

Flowering plants (angiosperms), the most diverse division, are subdivided into six classes. For practical purposes, however, they can be subdivided into two main classes: monocotyledons (grasses, palms, lilies, and orchids) and dicotyledons, which comprise all other flowering plants. The terms *monocotyledon* (monocot) and *dicotyledon* (dicot) mean "one seed leaf" and "two seed leaves," respectively. Thus, the first shoots that arise from monocot seeds have a single leaf, whereas those from dicot seeds have a pair of leaves. Also, monocots are characterized by one seed leaf, flower parts usually in threes or multiples of three, vascular tissues arranged in scattered bundles, and usually parallel leaf veins. Dicots are characterized by two seed leaves, flower parts usually in fours or fives or multiples of these, vascular tissues usually arranged in concentric zones or rings with a cambial zone, and a branched or netted pattern of leaf veins (figs. 2.6, 2.18). In addition, monocots and dicots differ in certain physiological processes.

At the family level of classification, a number of structural and cultural similarities among related genera of plants often become evident. For example, a well-known family of monocots are the grasses (Gramineae), and a well-known family of dicots includes roses, apples, pears, and firethorn (Rosaceae). (Family names, unlike the genus and specific epithet, are never italicized; the Latin form of a family name is capitalized, but the English, or common, family name is not.) Although these two families are very different, the individuals within them have many similar structural features, cultural requirements, and pest problems.

The scientific system of plant classification can be a very useful tool to horticulturists for identifying unknown plants, communicating clearly about plants, and developing or understanding the cultural practices and problems associated with a given plant.

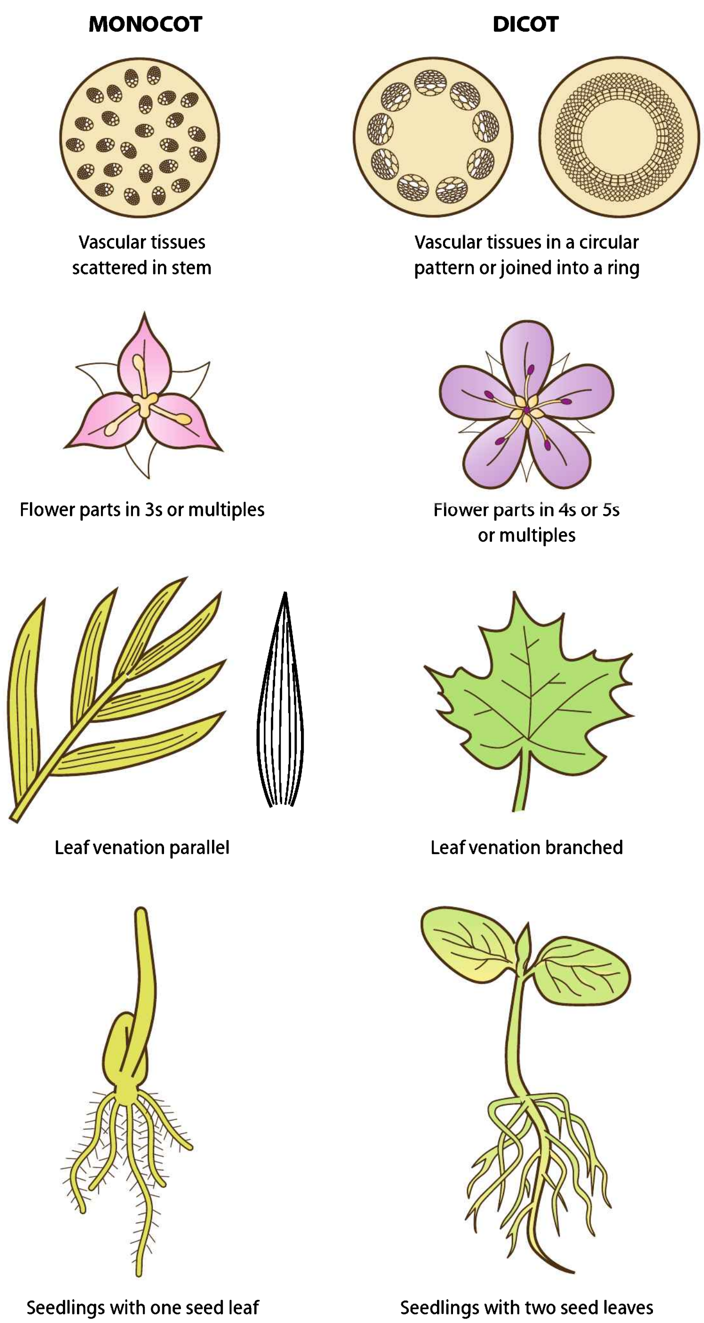
Plant Growth

Plant growth is an irreversible increase in plant size caused by an increase in cell number or size, which results in the development of new or expanded plant tissues,

organs, or other structures. The process of growth is controlled by the integration of a plant's genetic potential and the surrounding environmental conditions. Plant growth requires a source of water, carbohydrates, chemical energy, and mineral nutrients. In green plants, the essential physiological processes responsible for producing and using these items are carried out in individual cells, multicellular tissues, and organs.

Figure 2.18

Differences between monocots and dicots.



Photosynthesis

Photosynthesis is the process by which green plants produce their own carbohydrates, or nutrients, and obtain a source of chemical energy. Plant cells, in the presence of chlorophyll and light, convert carbon dioxide (CO_2) and water (H_2O) to carbohydrates (simple sugars), thereby transforming light energy into stored chemical energy. Energy is stored in the chemical bonds of the carbohydrate molecules ($C_6H_{12}O_6$) that are synthesized in the process. A by-product of this reaction is the evolution of free oxygen (O_2) (fig. 2.19). The chemical equation that describes photosynthesis is

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6\ O_2$$

In order for photosynthesis to occur, the stomata must be open to allow carbon dioxide to enter the leaf, adequate light must be striking the leaf, and water must be available to the plant. Plant species vary somewhat in the light levels needed for optimal photosynthesis. In addition, certain mineral elements must be present in adequate concentration for photosynthesis to occur efficiently. Information provided in chapter 3, "Soil and Fertilizer Management," clarifies the importance of minerals in photosynthesis, as components of chlorophyll molecules, and as catalysts of the process.

The chemically rich carbohydrates formed in photosynthesis are metabolized then combined with certain essential mineral elements (e.g., nitrogen, sulfur, magnesium, phosphorus) to

- synthesize more-complex compounds needed to produce new cells (growth); or
- be converted to more-complex carbohydrates (sugars and starch) or fats and stored in fruit, seed, stems, or roots; or
- be biologically combusted to release the chemical energy needed for cells to function.

Respiration

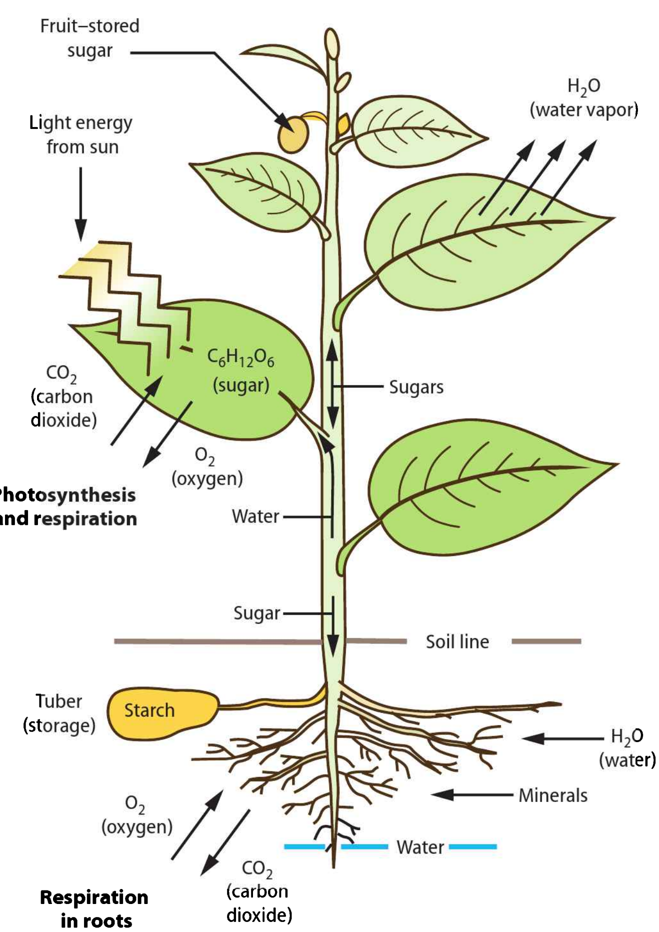
Respiration is the process in which chemical energy is obtained from the controlled biological breakdown of carbohydrates. Superficially, it is the reverse process of photosynthesis. Respiration is accomplished in cells through a complicated series of reactions regulated by enzymes. Complex carbohydrates are broken down into simple carbohydrates (sugars), carbon dioxide, and water. The energy released is used in many other cell processes and functions. In plants, respiration normally uses oxygen along with carbohydrates (see fig. 2.19). The chemical equation that describes respiration is

$$C_6H_{12}O_6 + 6\ O_2 \xrightarrow{\text{enzymes}} 6\ CO_2 + 6\ H_2O + \text{Energy}$$

The relative rate of respiration depends largely on temperature and the availability of oxygen and carbohydrates. It nearly doubles for every 18°F rise in temperature between 40° and 96°F (fig. 2.20). At any given temperature, plant tissues also vary in their respiration rates, with the highest rates occurring in rapidly growing tissues and the lowest in dormant ones. Respiration occurs at all times in living material, including plant parts removed from the plant during harvest. For recommended storage conditions (temperature, length of time, preservation methods) of produce, see table 13.2. These recommendations are based on scientific knowledge of postharvest respiration and pathology.

Figure 2.19

Schematic representation of photosynthesis and respiration. In photosynthesis, which occurs in green leaves, light energy is converted to chemical energy, and oxygen (O_2) is liberated. Carbon dioxide (CO_2) from the air and water (H_2O) taken up by the plant's roots combine in the presence of light and chlorophyll (which reflects the color green) and other cofactors to synthesize sugars—carbohydrates such as glucose ($C_6H_{12}O_6$)—and release oxygen as a by-product. The sugars synthesized in photosynthesis are translocated throughout the plant and are often converted to starch in storage organs such as fruits or tubers. Respiration occurs in all plant cells above and below the soil line. Carbohydrates such as glucose react with oxygen in the presence of enzymes to release chemical energy and carbon dioxide as a by-product. The energy released serves as fuel for plant growth and developmental processes.



Cycling of Photosynthesis and Respiration

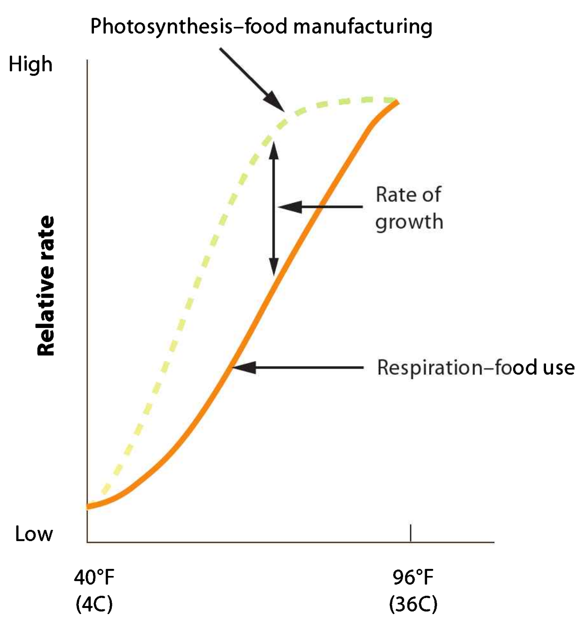
Photosynthesis and respiration form a cycle by which plants acquire the basic building blocks and the energy needed for growth and development. The photosynthetic portion of the cycle requires light, which typically peaks during midday and ceases at night and at nearly dark periods of the day. Meanwhile, respiration occurs 24 hours a day at variable rates, depending largely on temperature. In order for a plant to grow and develop normally, photosynthesis must occur at a rate that greatly exceeds respiration so that enough stored energy and carbohydrates are available to support nighttime respiration and other growth and development processes (see fig. 2.20).

While photosynthesis occurs only in tissues and organs with chlorophyll (i.e., leaves, stems, and some fruits, flowers, and surface roots), respiration occurs in all

living tissue, including underground roots. An adverse imbalance between photosynthesis and respiration can occur for various reasons. If water becomes limited during the plant's growing season because of drought or damage to the root system while the temperature remains seasonal, respiration could easily exceed photosynthetic production and cause a decline in vigor. Similarly, if roots are deprived of adequate oxygen because of high soil water content or compaction of soil, root respiration and consequently root function cease, causing plant water stress and other undesirable effects. If this daily cycle is unbalanced for a prolonged period, plant growth and development stop unless the plant has sufficient stored food reserves (e.g., complex carbohydrates, starches, fats, oils) that can be used. Without such reserves, plants typically become severely stressed and enter premature dormancy or die. The use of stored food reserves may reduce the vigor of a plant and its ability to develop high-quality flowers, fruit, seed, or storage organs such as tubers.

Figure 2.20

Relationship of respiration, photosynthesis, and plant growth to temperature.



Water and Nutrient Uptake

Plant growth and development depend on the availability of water and several essential mineral nutrients. These mineral nutrients are needed in various processes, including photosynthesis and respiration, and are combined with carbohydrates produced by photosynthesis to form important compounds.

Plants obtain all of their water and most of their mineral nutrients from the soil. Most of the water and mineral uptake occurs in roots along the very small fibrous portions of a plant's root system through a combination of chemical and physical processes. Some of these processes require root cells to expend chemical energy. Most of the soil water, however, moves into the plant passively by diffusion or movement along a force gradient. Soil water is pulled from the soil up through the plant and out of the stomata by means of this force gradient. Some of the plant's essential mineral nutrients are dissolved in the soil water and are transported to the root surface during this process. Nutrients also move to the root surface by diffusing along a concentration gradient or by physically contacting growing root tips. Once nutrients are near the root surface, their uptake by the roots often involves the expenditure of chemical energy in a process known as active uptake.

Transpiration

Transpiration, the evaporative loss of water vapor from plant leaves through the stomata, is closely related to the translocation of water and dissolved minerals from the roots through the xylem. Water moves along a force gradient from relatively high in the soil and root area to relatively low in the air and leaf area. A continuous, flowing column of water is maintained in the xylem as long as the stomata are open and water is available in the soil. The transpiration process depends on the unique properties of water that allow a long column of water to be pulled

up like a thread from the roots to the top of the plant. Coast redwoods, for example, can have a column more than 300 feet long (see also "The Plant Water Cycle and Evapotranspiration" in chapter 4, "Water Management").

The rate of transpiration depends on environmental factors that affect the evaporation rate (sunlight, temperature, relative humidity, wind, etc.) and the degree of stomatal opening, as well as the amount of available soil water. Transpiration ceases at night in most plant species adapted to temperate climates because their stomata are closed. Transpiration helps cool plants on hot days and transports minerals from the soil and organic compounds produced in the roots to plant cells.

In succulents and some other plants native to hot climates, stomata are open at night and closed during the day (the opposite of the temperate pattern), allowing carbon dioxide used in photosynthesis to accumulate in leaves at night and reducing water loss via transpiration during the day.

Translocation

Translocation is the movement of water, mineral nutrients, food (carbohydrates), and other dissolved compounds from one part of the plant to another. It can occur from cell to cell in the space between cells, but it takes place largely in the xylem and phloem tissues. By this process, water and essential mineral nutrients are distributed from the roots to other tissues, and carbohydrates produced in the leaves are moved to meristematic areas (shoot and root tips, cambium, buds), storage organs (fruit, seed, stems, and roots), and other tissues in need. Certain externally applied substances (e.g., systemic pesticides) may enter some plant parts and be moved to others by this process.

Plant Development

Like growth, plant development is an integrated expression of a plant's genetic potential and its environment. Although horticultural plants vary widely in their specific growth and development patterns, all are basically annuals, biennials, or perennials that go through vegetative and reproductive phases of a growth cycle. Vegetative growth involves the development and increase of root, stem, or leaf tissues, whereas reproductive growth involves the development and increase of flower, fruit, and seed tissue. A generalized growth and development cycle starts with seed germination and proceeds through juvenility, maturity, flowering, and fruiting. Once the fruit matures, the cycle is essentially completed. For annual plants, the development of fruit is followed by the final phase of growth, which is senescence and death. For perennials, the vegetative and reproductive phases of a growth cycle may be repeated each year, or each phase may continue for more than a year.

Internal Regulation of Plant Growth and Development

Although growth and development are indirectly controlled by the availability of light, water, carbohydrates, chemical energy, and mineral nutrients, hormones provide direct internal regulation of these processes. Plant hormones (sometimes called phytohormones) are produced in one plant part or organ and are translocated to another part where they have a pronounced effect. Plant hormones are effective in relatively small quantities and provide control or regulation of most plant processes. The five major groups of plant hormones—gibberellins, auxins, cytokinins, ethylene, and abscisic acid—and their major effects on growth and development are listed in table 2.1. The production of hormones often occurs in meristematic tissue or meristems or other new-growth regions and is sometimes triggered by specific environmental conditions. Plant age and species also dictate the type and amount of hormone that is produced. Depending on the amount present, the hormone's effect may be dra-

matically different. For example, at low concentrations, auxins promote root formation, but at higher concentrations, they can kill broadleaf weeds (see table 2.1).

Dormancy

Plant growth is not always continuous, though it is in many tropical and semitropical plants. Shoots, buds (leaf and flower), and other vegetative parts of a plant that are alive but not actively growing are said to be dormant. Seeds that are alive and viable and yet do not germinate are also dormant. Dormancy is a mechanism by which plants survive unfavorable environmental conditions and seeds delay germination until they are in a favorable environment. In order to survive such periods, a plant or seed must contain sufficient stored food reserves (carbohydrates) to support ongoing low-level respiration.

Seed dormancy may be physical, physiological, or a combination of the two, depending on the plant species. Physical dormancy is most frequently caused by a hard, impervious seed coat that prevents water or oxygen from entering the seed. Several treatments can be applied to seeds that are physically dormant. Physiological dormancy may be caused by special internal processes, certain plant hormones, or other inhibitory compounds that are present in the seed or fruit. Sometimes physiological dormancy is caused by the presence of an immature embryo in the seed, and the seed must first go through an after-ripening process before an embryo can develop fully. More commonly, the hormone abscisic acid or some other inhibitory compound is present in the seed, and a specific set or series of environmental conditions (i.e., cold, heat, rainfall, etc.) must occur to either remove the substances or trigger physiological processes that overcome them.

Dormancy of plants is usually triggered by the onset of unfavorable environmental

Table 2.1.

FIVE GROUPS OF PLANT HORMONES AND THEIR EFFECTS

Hormone group	Effects
auxins	regulate cell enlargement suppress lateral bud development, creating apical dominance of main buds and shoots direct shoot growth toward a light source direct horizontal growth upward suppress fruit or leaf drop mechanisms promote formation of adventitious roots from stems or leaves low concentration: promote root formation high concentration: kill broadleaf weeds promote fruit set and development or fruit abortion, depending on the plant species
gibberellins	regulate cell division and stem elongation promote flowering in some plant species activate enzymes in germinating seeds
cytokinins	stimulate cell division, frequently in conjunction with auxins and gibberellins to regulate processes listed under each of those
ethylene	accelerates fruit ripening induces flowering in some species hastens senescence and abscission of leaves and fruits interacts with auxins in certain processes often produced by plants or plant parts that have been injured
abscisic acid	regulates and promotes dormancy in shoots and seeds responsible for abscission (dropping-off) of leaves on deciduous plants and closing of stomata on leaves of plants under severe stress

conditions, such as the shorter days and colder weather of autumn and winter or inadequate soil moisture that may severely stress plants during summer droughts. Once sufficient hours of cold temperatures (usually at or below 45°F) have accumulated and warmer weather returns, winter-dormant plants resume growth. Similarly, plants that are dormant because of drought stress may resume growth once sufficient soil moisture is restored.

Because of apical dominance, many lateral buds remain dormant and lateral shoots show reduced vigor under favorable growth conditions until the terminal bud or shoot is removed. Removing terminal growth removes the source of auxin production that has been suppressing the lateral growth (see table 2.1).

Vegetative Development

For annual and biennial plants as well as some perennial plants, the vegetative growth phase begins with seed germination or the breaking of leaf buds and ends with the initiation of flower development. In woody perennials, vegetative and reproductive phases often exist concurrently. Seeds and buds are usually dormant until specific environmental conditions are present or a series of environmental conditions and physiological processes occurs. Dormant seeds and buds are alive and respiring. Seeds depend on internal stored food reserves to survive, whereas buds have access to food compounds produced or stored by the plant.

Seed Germination

Annual plants and most biennial plants begin their growth and development at seed germination. Many perennial plants also begin their first growth cycle this way. Seeds capable of germination are said to be viable. They contain a living embryo that is respiring at a low level.

Germination starts when a seed first takes in water and ends when the seedling is self-sustaining. Before germination can occur, a seed must be surrounded by suitable environmental conditions. The environmental factors affecting seed germination are water, oxygen, temperature, and light. All species require a continuous supply of oxygen and water for germination, but they vary considerably in their temperature and light requirements. Usually, a species needs the temperature to remain within a certain range, rather than at a specific degree, in order to germinate. Germination rates under optimal environmental conditions vary among species, but the relative rate of germination for a species is determined largely by how closely the surrounding environmental conditions match the optimal ones.

Juvenility

A plant is considered juvenile from the time it is a seedling until it is mature and capable of initiating flowers. Juvenility is the portion of the vegetative growth phase marked by relatively vigorous, uninterrupted growth (except for normal seasonal dormancy). In annual species, juvenility may last for a few weeks to a few months. In perennial plants such as fruit trees, juvenility may last for a few years. A small number of plants, such as bamboo and agave, remain juvenile for 10 years or more.

Some species exhibit distinctly different morphological features during juvenility and maturity. Juvenile pears may have thorns, whereas mature ones do not; leaves of *Hedera* species are clearly lobed on juvenile plants and smooth on mature ones, but the opposite occurs in *Philodendron* species. Juvenile *Hedera* stems are trailing and require support to grow upright, whereas mature stems freely grow upright with no support.

As a general rule, juvenile plants or plant parts more readily initiate adventitious roots than do mature plants or plant parts. Juvenile plant parts are also more readily grafted than are older sections of the plant.

Maturity

Maturity is reached when the plant is fully developed and is capable of initiating flowers. Certain morphological and physiological changes may occur in mature plants. During the mature phase of vegetative growth, bulbs, tubers, fleshy roots, and runners are produced by horticultural crops with the genetic potential to do so (see fig. 2.3).

Although a plant is capable of developing flowers and other specialized organs when it reaches maturity, it may not do so. The environmental conditions at maturity usually control whether the plant will flower or develop specialized organs.

Reproductive Development

Flower, fruit, or seed production is the goal for growing many horticultural plants. Understanding reproductive physiology and how reproductive development may be manipulated is therefore very important to horticulturists and home gardeners.

Flower Induction

In flowering plants, the reproductive growth phase begins when certain vegetative meristems (actively growing shoot tips or buds) are induced to produce reproductive organs (flowers), and it ends with the formation of fruit or the senescence of the plant. Once a meristem is induced to flower, it follows a process of initiating cells that form new tissues of a flower or a flower cluster, known as an inflorescence. The process is normally irreversible after it is initiated. In other words, the meristem will no longer initiate the vegetative cells of shoots it initiated previously. The length of time needed to induce a meristem to become reproductive and the length of time needed for induced meristems to produce flowers vary among species from a few weeks to several months. These time frames may also vary slightly within a species, depending on temperature or other factors. The number of meristems on a plant that are induced to flower may also vary widely from plant to plant.

Home gardeners should know the time of year when flower induction occurs and the length of time from induction to flowering for a given species. Many perennial plants initiate cells of flower tissue within meristems months before flowers develop. Flower buds of spring-flowering woody plants, for example, are usually initiated the previous summer. Pruning such species during winter months reduces the number of flowers they produce in the spring. Annual plants, however, may reach maturity and flower within several weeks of seed germination.

Flower and Fruit Development

Some plant species are self-induced to flower and are not greatly influenced by environmental factors. In many other species, a number of factors, aside from a plant's genetic potential, control flower induction and development. The primary factors are day length (the photoperiod, or the number of daylight hours), light intensity, temperature, soil moisture content, and the internal nutritional status of the plant. Many of these factors also influence the development of fruit from flowers.

Once a flower is developed and opens fully, a number of events must take place for a fruit to develop. As noted earlier, the ovary of the flower, and sometimes other flower parts, matures to form a fruit. For normal fruit development, the flower's stigma must receive viable pollen, which in turn must germinate and fertilize the ovule(s) (see fig. 2.13). Fertilization is not assured even when pollination takes place. Each ovule must be fertilized by a separate pollen grain. Several physiological processes are initiated upon pollination; these processes result in the inhibition of flower or fruit drop, known as fruit set. Fertilization does not always occur even though pollination and fruit set take place.

Pollination and fertilization are complex processes that require precise environmental conditions to proceed normally. After ovules in the flower are fertilized, the size of the developing fruit increases rapidly. The raw materials and energy needed for this growth are supplied by the plant's photosynthesis. The nutritional status of the plant and moisture availability greatly affect fruit size and quality. There must be a sufficient number of leaves to produce the photosynthetic products needed to support developing fruit and to meet the other basic needs of the plant. For example, it has been calculated that a minimum of 40 illuminated leaves are needed to support the growth of one apple on a mature tree. Adequate soil moisture must be available for the same reason, or fruit may be small and poorly developed or may drop prematurely.

It is possible, though less common, for fruit development to continue without fertilization. No seed develop in this situation, which results in seedless fruit. A few crops normally develop fruit without ovule fertilization, including bananas, navel oranges, some grapes, pineapple, persimmon, and some cucumbers. Fruit set may occur even though only a portion of the ovules are fertilized, which results in small or misshapen fruit, as is common in some tomato cultivars.

Only a fraction of the flowers normally produce mature fruit in most tree fruit crops. A significant number of fruit drop from tree fruit crops just after the petals fall (or about 4 to 6 weeks later) in what is known as June drop. Even when fertilization appears to have been completed, plants may drop some or all of their immature fruit. Incomplete or faulty fertilization, internal nutrition imbalances, water stress, or temperature extremes may cause fruit drop. However, fruit drop during the early stages of development may be normal and may serve to adjust the fruit load to a level that the plant can adequately support.

Flowers may be self-pollinated or cross-pollinated; most plants are cross-pollinated. In self-pollination, pollen from a plant usually pollinates a flower of that same plant. This is common in beans, eggplant, peas, peppers, and tomatoes. In cross-pollination, pollen from one plant normally pollinates flowers of another plant of the same species. Wind and insects (particularly honey bees) are usually important in cross-pollination. Species that normally cross-pollinate have more genetic variation among plants and have a greater chance of adapting to long-term changes in the environment. A number of physical and physiological plant characteristics ensure that cross-pollination occurs. Self-incompatibility in many temperate tree fruit varieties is a good example. Entire varieties of these crops are often self-incompatible, so two or more varieties must be interplanted to allow cross-pollination between varieties.

Fruit Quality and Ripening

As a fruit matures, sugars and aromatic compounds that contribute to flavor begin to accumulate. During this final development phase, the ripening fruit typically changes color and may soften. Fruit of some species may be picked from the plant when they are physiologically mature but not fully ripened, and they will develop good eating quality (e.g., tomatoes, bananas, pears, avocados, apples). Fruit of other crops must be allowed to fully ripen on the plant in order to reach good eating quality (e.g., grapes, citrus, strawberries). Adequate soil moisture, sunny days, and, for many fruit crops, cool nights, are necessary during the ripening stages to ensure that fruits are sweet and have good flavor and color. Environmental conditions that maximize photosynthetic sugar production and minimize its loss through respiration result in high-quality fruit.

Two widely held notions are that planting cantaloupes near cucumbers will result in poorly flavored melons, and planting a yellow-fruited apple tree near a

red-fruited one will result in poorly colored fruit. Neither of these beliefs is true: Cross-pollination does not occur between cantaloupes and cucumbers; when cross-pollination occurs between yellow- and red-fruited apple cultivars, only the resulting seed and the offspring from it are affected, not the fruit, since the fruit develops from the tissue of the mother plant. Poor flavor in melons and poor color in apples most often occur when plants are diseased, fruit are harvested too immature, or cloudy, cool weather persists during the final ripening period.

How Plants Function

Environmental conditions and plant nutrition can dramatically influence plant growth and development. These factors can greatly influence when a plant switches from the vegetative growth phase to the reproductive growth phase. Light, temperature, soil moisture content, and nitrogen nutrition are the principal factors that affect plant development. Two or more environmental factors often interact in complex ways to impact the growth and development of a given plant. The regulatory mechanisms in plants that are influenced by environmental conditions are not fully understood, because they involve a series of biochemical processes and interactions with plant hormones whose effects depend on their concentration. At a low concentration, a hormone may induce a particular response, and at higher concentration it may inhibit that same response.

As discussed previously, the degree to which flowering or other developmental processes are induced by environmental conditions varies among plant species. These processes are largely self-induced in some plants and are not significantly influenced by environmental factors. For many horticultural plants, a great deal of effort focuses on controlling or manipulating environmental or nutritional factors that promote the development of desirable plants or plant parts. For other plants, their entire growth cycle may be carefully scheduled so they reach maturity in the season that naturally provides the environmental conditions that promote flowering or other desirable growth and development phases.

Plant Responses to Day Length

Some horticultural crops initiate flowers, form specialized vegetative organs, or initiate dormancy in response to a specific length of daylight in a 24-hour period (a photoperiod). Such plants are called photoperiodic. Plant leaves are the sensors or receptors of critical photoperiods, and the stimulus is transported by some unknown biochemical or hormonal mechanism to meristems. A number of successive days (often 60 or more) in which the critical photoperiod occurs is needed before the specific organ initiation occurs. Once a particular plant response is induced, altering the photoperiod does not interfere with the growth response that was initiated.

Short-day plants are induced to flower or develop other special organs in response to a succession of days that have a light period less than 12 hours long. Conversely, long-day plants are sensitive to photoperiods that are 12 hours or longer (usually 14 hours or more). Many plants are called day-neutral because their flowering or other developmental processes are not affected by specific day lengths (table 2.2).

The natural leaf drop and color change responses of deciduous plants in the fall are largely short-day responses. Recall that leaves get their green coloration from the presence of chlorophyll. As day length shortens during late summer and fall, deciduous plants are induced to stop chlorophyll production in their leaves and develop a zone of special cells at the base of the leaf petioles that allows the leaves to separate from the plant. The consequences are a loss of green color that

unmasks other leaf pigments and the eventual dropping of leaves.

Knowledge of photoperiodic responses has been used widely in the commercial chrysanthemum industry. Although chrysanthemums are short-day plants, fresh-cut flowers are now available year-round. When the natural photoperiod is less than 12 hours, growers use artificial lighting to maintain long days until the plants reach the desired height. Growers then stop the lighting, and the plants receive natural short-day conditions that induce them to flower. When natural photoperiods are too long for the mums to initiate flowers, growers cover plants of the desired size with black cloth at about 5:00 p.m., artificially shortening the days and inducing the plants to flower.

Photosynthesis and transpiration are affected by day length. Theoretically, total photosynthetic production and the amount of water transpired are lower on short days than on long days if everything else is held constant. Photosynthesis uses light directly, but transpiration depends on light to trigger the opening of stomata, which enables transpiration to occur.

Vegetative growth responses that are controlled by photoperiod in some species include seed germination, tuber formation, bulb formation, shoot dormancy, leaf abscission, and runner and stolon development.

Table 2.2.

LONG-DAY, SHORT-DAY, AND DAY-NEUTRAL PLANTS

Category	Common name	Scientific name
long-day	bentgrass	*Agrostis palustris*
	coneflower	*Rudbeckia bicolor*
	dill	*Anethum graveolens*
	fuchsia	*Fuchsia hybrida*
	ryegrass, perennial	*Lolium perenne*
	sedum	*Sedum spectabile*
	spinach	*Spinacia oleracea*
short-day	chrysanthemum	*Chrysanthemum morifolium*
	cosmos	*Cosmos sulphureus*
	kalanchoe	*Kalanchoe blossfeldiana*
	poinsettia	*Euphorbia pulcherrima*
	strawberry (June-bearing)	*Fragaria × ananassa*
	violet	*Viola papilionacea (V. cucullata)*
day-neutral	bluegrass, annual	*Poa annua*
	Cape jasmine	*Gardenia jasminoides*
	corn (maize)	*Zea mays*
	cucumber	*Cucumis sativus*
	fruit and nut trees	
	grapes	*Vitis* spp.
	strawberry (everbearing)	*Fragaria × ananassa*
	tomato	*Lycopersicum esculentum*
	Viburnum spp.	*Viburnum* spp.

Plant Responses to Light Intensity

The intensity, or brightness, of light influences a number of processes and qualitative characteristics of horticultural plants. A widely used unit of light intensity is the foot-candle (f-c). Full sun measures about 10,000 foot-candles and overcast conditions produce about 1,000 foot-candles; bright, naturally lighted interiors are typically 400 to 1,000 foot-candles, whereas poorly lighted interiors are as low as 30 foot-candles. Plants have an optimal range of light intensity in which they grow and develop best. If light conditions are consistently beyond either end of the optimal range, the plant will not grow normally and may eventually die. Horticulturists strive to place plants where they will receive near-optimal light intensity, or they manipulate the light by supplementing it or by providing shade to produce near-optimal levels.

Light intensity may affect plants at any developmental stage, depending on the species. For a few species, seed germination is inhibited by the presence of light, whereas in a few others, it is required for germination. As light intensity increases, air and leaf temperatures often increase, stomata open fully, and the relative rate of transpiration may increase. For many fruit, vegetable, and ornamental crops, high light intensity is necessary for development of maximum color and for the highest sugar levels and best flavor in edible crops. Leaves of plants that are in full sun all day are often relatively smaller in area and slightly thicker than those on the same plant that are shaded all day.

Shoot bending in response to light is

very common. The mechanism is believed to be linked to larger auxin concentrations on the shaded side of the stem. Light apparently stimulates either a transfer of auxin to the shaded portion of a stem or a breakdown of auxin on the lighted portion of the stem. In either case, the higher auxin concentration on the shaded stem portion stimulates growth, causing the stem to bend toward the light source.

At relatively low light intensities or in shaded conditions, shoots of plant species that are not adapted to shade become elongated and thin. This stretching of shoots causes them to be weak, less vigorous, and spindly and results in a plant that is of very low quality. Plants of such species may die if more intense light is not provided.

Many plants adjust to a change in light intensity if the change is gradual. Abrupt changes in light intensity may harm foliage. In most plant species, reducing light intensity abruptly causes leaf drop, whereas an abrupt increase in light intensity causes leaf yellowing or sunburning.

Plant Responses to Light Quality

Light quality is an expression of the color of the light source. Sunlight has equal amounts of all colors and appears white. Most artificial light sources do not have a balance of all colors and impart some color other than white. Because photosynthesis is most efficiently conducted with red and blue light, reddish-blue fluorescent light bulbs have been designed specifically for growing plants under artificial lighting. Recent research, however, has demonstrated that cool-white fluorescent lamps are actually the most effective for growing foliage plants without natural light.

The color of light can affect seed germination in a few plants. Blue and red light stimulate or inhibit germination, depending on the species. Under natural full-sun conditions, enough red and blue light is present to cause these effects.

Plant Responses to Temperature

Many plant growth phases and physiological processes are controlled or affected by temperature. The effects of temperature on a sensitive species usually depend on the length of time that a critically high or low temperature is maintained. Plant metabolic processes gradually shut down in many species as temperatures exceed 96°F or drop below 40°F.

The respiration rate in plants and other organisms greatly depends on temperature. Within the range of 40° to 96°F, the respiration rate doubles for every 18°F increase in temperature (see fig. 2.20). Growth rates of healthy plants also increase as temperature increases within a species' critical temperature range. Harvested crops (vegetables, fruits, cut flowers, etc.) remain alive and continue to respire stored carbohydrates after they are removed from a plant. Holding these products at low, near-freezing temperatures until they are used can greatly extend their shelf life quality because respiration is significantly reduced. Some crops of tropical origin (e.g., tomatoes and bananas) may be injured or lose quality if storage temperatures are too cool, however. For optimal temperatures in vegetable crops, refer to table 13.2.

Transpiration in many species also increases as temperature increases, provided there is adequate soil moisture. The stomata of some species close during hot daylight hours even though the sun remains bright. This reaction halts transpiration and provides a drought-avoidance mechanism for such species.

Seed germination in some species is controlled by temperature. Many temperate species produce seed that require several weeks of exposure to cold (45°F or less) moist soil in order to break dormancy and germinate, a process called stratification. Seed of a few species, like lettuce, express a high temperature dormancy if they are exposed to soil temperatures that are too warm, usually above 85°F.

Dormancy of buds and shoots of deciduous plants is generally controlled by

temperature. Although photoperiod triggers the onset of dormancy in these plants, a certain amount of cold exposure is necessary to break their dormancy. These chilling requirements vary widely among species and are important characteristics to know for most varieties of temperate tree fruit crops. Buds and shoots of these species remain dormant until a critical number of hours (typically 200 to 800) of cold temperature (usually below 45°F) accumulates. The occurrence of warm temperatures between episodes of cold, such as day-night fluctuations, before the chilling requirement is met does not offset previous cold hours unless they are unseasonably warm (see the section "Dormancy and Winter Chill" in chapter 16, "Temperate Tree Fruit and Nut Crops").

In some plants, an exposure to cold temperatures for a sufficient period (usually 40° to 50°F or colder for 6 to 12 weeks) is required before they will initiate flowers. This phenomenon, known as vernalization, usually controls flowering in biennial plants. Active shoot meristems are the receptor for this stimulus. Vernalization can be reversed if plants are subsequently exposed to high temperatures. Onion growers use this knowledge commercially. Onion sets are commonly stored for several weeks after harvest at near-freezing temperatures to reduce respiration and retard spoilage. The sets are vernalized during this time and prematurely flower (or bolt) if they are not devernalized before spring planting. After removal from cold storage in the spring, the sets must be exposed to temperatures above 80°F for 2 to 3 weeks to devernalize them and facilitate bulb formation. Similarly, onion seedlings exposed to cold temperatures under 50°F for at least 10 days, then exposed to warm temperatures and lengthening days, will be induced to flower before maturing and bulbing. Thus, the timing of planting onion seed and transplants is critical, and it is complicated further by variations in day-length requirements among cultivars, as discussed in chapter 13. The development of flowers and fruit is also often affected by temperature, as extremes in temperature can reduce or inhibit pollination and fruit set in crops. Color development, particularly red pigments in flowers and fruits, can be inhibited by high temperatures during the maturation period. Color intensity is typically enhanced by clear, bright, moderately warm days and cool nights.

Interactions of Photoperiod and Temperature

Temperature can interact with light to modify plant responses to a given photoperiod. Poinsettias initiate flowers in 65 days when grown in short days at 70°F but require 85 days if the temperature is 60°F. June-bearing strawberry cultivars initiate flowers under short-day conditions and runners under long-day conditions unless temperatures remain below 67°F. At temperatures below 67°F, these cultivars initiate flowers under any day-length conditions. In similar fashion, flower initiation in Christmas cactus is a short-day response when night temperatures are 60° to 65°F, but plants will flower at any day length if temperatures are 55°F or below; at nighttime temperatures of 70°F or above, no flowering occurs regardless of photoperiod.

Plant Responses to Soil Moisture Conditions

All plant growth and development processes are adversely affected when soil moisture is inadequate or when a plant's root or vascular system becomes impaired and cannot supply adequate amounts of water to plant tissues. Photosynthesis, transpiration, and nutrient uptake are among the processes first affected by insufficient water. As plant tissue becomes drought stressed, it usually becomes less succulent; for example, leafy vegetable crops become tough when water is limited. A reduction in the rate of growth in shoots and roots, poor fruit set, and poorly developed flowers, fruits, or storage organs

follow closely afterward. Without adequate moisture in the soil, seeds will not germinate. In general, plants suffering from drought will be stunted and turn light green or grayish green, and leaves and shoots may wilt.

Plant Responses to Carbon Dioxide and Oxygen Concentrations

Carbon dioxide is essential for photosynthesis, and oxygen is essential to all plant tissues for respiration. Air surrounding plants, including indoor air, normally supplies adequate amounts of these two gases to the shoots of plants. However, the soil surrounding plant roots does not always contain enough air to provide adequate amounts of oxygen to plant roots. When soil is severely compacted, waterlogged, or artificially deepened more than a few inches over a plant's root system, oxygen may be insufficient for root respiration. Roots die if these conditions occur for an extended period. Germinating seeds also require oxygen because they are respiring. Thus, the soil or propagation media in which they are placed must be well aerated.

The fact that respiration requires the presence of oxygen is exploited to extend the shelf life of many horticultural commodities held in commercial storage. Remember that plant tissues and organs continue to respire even though they are removed from the plant. By removing the oxygen from the air in storage rooms or containers, the respiration rate of these commodities is stopped, and the product will remain fresh for a long time, so long as temperatures are kept cool to minimize spoilage and moisture is maintained to prevent dehydration.

Relationship of Nitrogen Nutrition to Plant Growth and Development

Abundant levels of available nitrogen stimulate growth of new root and shoot tissue and may lead to increased disease problems and reduced fruit quality. The presence of new vegetative growth usually inhibits initiation of flowers. If the nitrogen level in a plant subsides as new vegetative growth matures, the increased photosynthesis may produce an abundance of carbohydrates. At this point, flower initiation readily occurs, and photosynthetic production of carbohydrates is maintained to support flower and fruit development. However, if the nitrogen level of a plant subsides and little photosynthesis occurs, not enough carbohydrates are produced to support growth, flowering, and fruit development. Thus, a relative balance of nitrogen and carbohydrates is essential for a plant to flower readily.

Plant Responses to Stress

Stress can be defined as any combination of nonoptimal growing conditions for a given plant. Stress includes extremes in temperature, insufficient light or water, inadequate nutrients, poor soil aeration, or any combination of these factors. Under conditions of stress, a plant will have a shorter juvenile growth phase, low vigor, and weak, tough vegetative growth. A stressed plant may enter dormancy prematurely or remain in extended dormancy. Premature defoliation and abnormal color may occur under severe stress. In general, the quality of vegetable, fruit, and ornamental crops is reduced if severe or prolonged stress occurs.

Reproductive development is also affected by stress. Early flower initiation along with heavy flowering and fruit set often occur in plants under moderate to severe stress. However, the size and overall quality of flowers and fruit of stressed plants are often greatly reduced. Seed produced from stressed plants may be small or have low viability.

A short period of mild stress is often imposed on bedding plants and other plants just before they are transplanted into the landscape or garden. Withholding water and nitrogen fertilizer from plants along with gradual exposure to full sun is known as hardening. Hardening reduces plant growth and toughens plant tissues, helping plants survive transplanting.

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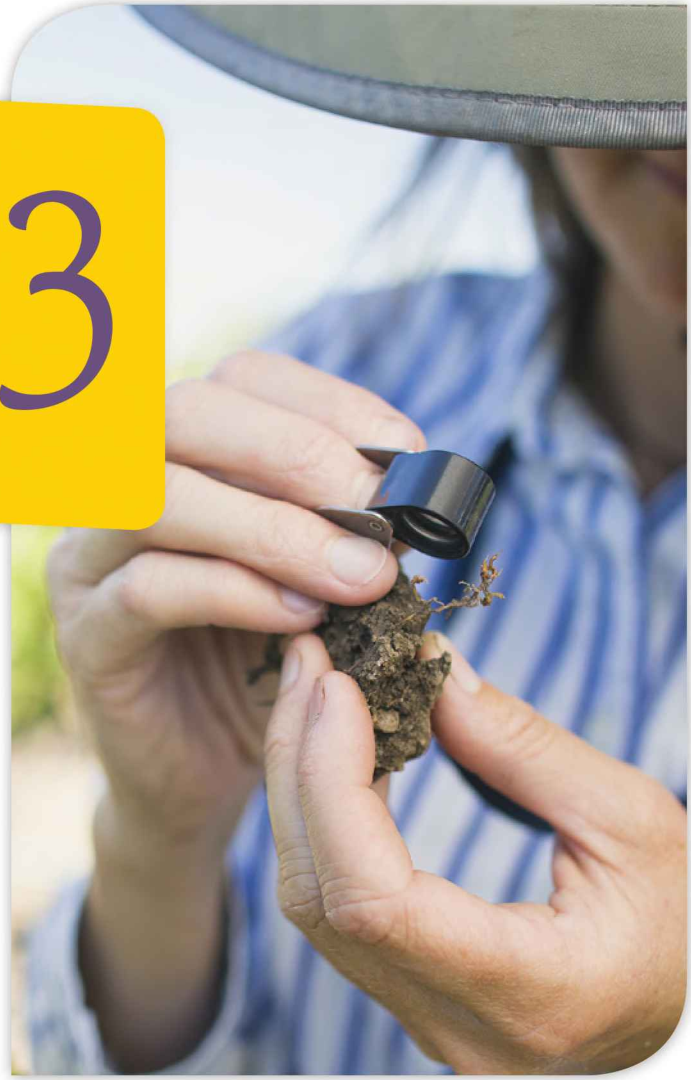
Soil and Fertilizer Management 3

Ben Faber, James Walworth,
Deborah D. Giraud, and Deborah Silva



Learning Objectives

Learn the four components of soil. Understand the basic principles of soil formation, soil function, and soil profiles.

Learn about the physical properties of soil and their effects on plant growth. Know the difference between soil texture and soil structure. Understand the basic properties of soil minerals, organic matter, cation exchange, and carbon-to-nitrogen ratio.

Develop an understanding of the basic concepts of soil water and its availability to plants in different soil types.

Learn the basic concepts of soil fertility and pH.

Learn the 17 essential elements needed by plants and their sources. Learn about essential nutrient function, deficiency, and toxicity symptoms.

Be able to define what a fertilizer is. Learn about fertilizer analysis, sources, formulations, and application methods. Understand the differences and similarities between organic and inorganic fertilizers and amendments.

Learn which nutrients are most often needed in fertilizers in California. Learn the basics of composting and rapid backyard composting.

Learn when and how to amend landscape soil, prevent compaction and structure breakdown, rejuvenate good structure, and manage lead contamination.

Soil and Fertilizer Management

An old adage has been stated in a number of University of California publications over the years: The successful gardener fertilizes adequately, but not excessively; irrigates thoroughly but not too frequently; mixes organic matter into the soil; and tills little when the soil is wet. This sage advice sums up many of the messages of this chapter.

Soil is the upper layer of earth that may be plowed and in which plants grow. Depending on the location, soil can be a few inches to more than 100 feet deep, overlying the rocks known as the Earth's crust. Soil is an important component of the environment. It is a complex, dynamic, natural material in which physical, chemical, and biological reactions are constantly occurring. Soil is created over thousands of years, primarily from disintegrated and decomposed rocks and organic matter. Different kinds of soil form in different locations because soil retains some of the chemical and physical characteristics of the parent rocks from which it derives and is subject to different climatic conditions. For example, in California the volcanic cinders in Tehama County give rise to a soil quite different than soil from the solid granite rock in Riverside County.

The principal components of soil are minerals, organic matter, air, and water. Soil minerals are derived from decomposed rocks. Soil organic matter consists of plant and animal residues in various stages of decomposition, along with living soil organisms (e.g., earthworms, fungi, bacteria) and the substances they synthesize. Together, organic matter, minerals, air, and water provide nutrients, moisture, and anchorage for plants. In different kinds of soil, these four components are present in varying amounts that can render the soil fertile and hospitable or deficient as a medium for plant growth.

Soil minerals and organic matter make up the solid part of the soil, and air and water occupy the pore spaces between the solid particles. Soil drenched by excessive irrigation or rainfall, or soil that does not drain freely, is waterlogged and has very little air in its pore spaces. During periods of drought, the percentage of air in soil pores is high and the percentage of water is low. A western soil with an ideal moisture content for plant growth is about equally divided between solid materials and pore space on a volume basis, with the pore space equally divided between water-filled and air-filled pores (fig. 3.1). Most California soil is mineral soil because it has an organic matter content that is less than 20% (and often less than 5%) by weight of the solid phase.

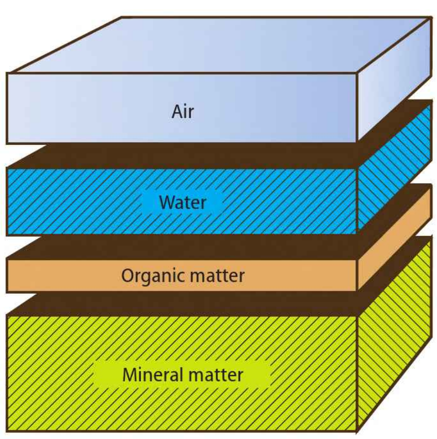


Figure 3.1

Four principal components of a representative mineral soil with ideal moisture content for plant growth. The pore space is 25% water and 25% air; the solid phase is 45% mineral matter and 5% organic matter.

Soil Formation

The development of soil from parent rocks, which can take thousands of years, starts with physical and chemical weathering of rocks into unconsolidated rock fragments. Soil formation, the gradual development of soil from parent materials, is a dynamic, continuous process consisting of four mechanisms: additions, losses, transformations, and translocations. Deposition of dust, leaves, animal remains, and so on adds new material to the surface of a soil, whereas erosion and water percolation can remove materials from the soil. Transformations occur as weathering continues, converting materials in the soil into new materials. Translocations occur as clays and dissolved materials are repositioned in the soil through the action of moving water. These four soil formation processes are influenced by five essential, natural factors:

- climate: temperature and rainfall
- organisms: microscopic and macroscopic plants, animals, bacteria, and fungi
- relief: topography of the land surface (affects runoff, drainage, and sunlight interception)
- parent material: rocks from which the soil formed
- time: period when parent materials are subjected to these processes

Interactions among these five factors were termed the CLORPT equation by the late Hans Jenny of UC Berkeley. Changes in climate, particularly temperature, can lead to cracking, chipping, swelling, and shrinking of the original parent materials. These physical changes break the rocks into smaller pieces, exposing a larger total surface area to the environment. The chemical action of water, oxygen, carbon dioxide, and various acids reduces the size of rock fragments and changes their chemistry (mineral composition). The metabolism of living microorganisms and the organic compounds associated with decaying plant and animal life contribute organic matter to the weathered rock material, and a true soil begins to form. Two definitions of soil given in a standard college textbook are "the collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time," and "a dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms" (Brady and Weil 1999, p. 855).

The properties of soil are closely related to the properties of the parent materials. Parent material influences the amount and kinds of nutrients naturally present to support plant growth, the soil's natural texture, and many other physical and chemical properties of the soil.

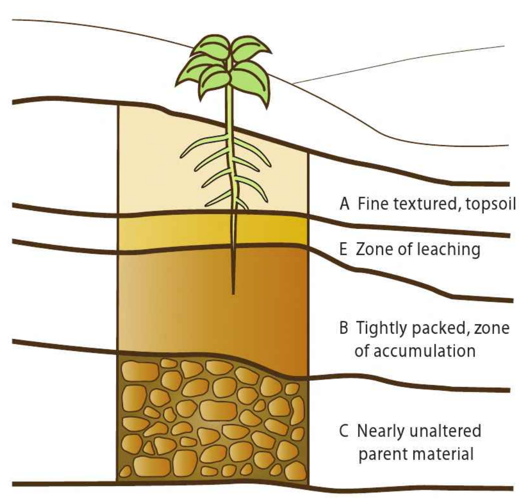
The soil formation process occurs over geologic time, hundreds and thousands of years. Nonetheless, we can observe the effects of human activities such as irrigation management and the addition of amendments and fertilizers on a soil's chemical and physical properties.

Soil Profile

A vertical section through a soil reveals its profile, as shown in figure 3.2. As soil ages,

Figure 3.2

A typical soil profile showing the four general soil horizons. A: Fine textured, topsoil; E: Zone of leaching; B: Tightly packed, zone of accumulation; C: Nearly unaltered parent material. *Source:* After California Fertilizer Association 1998, p. 4.



the profile is differentiated into distinct layers, or horizons, that can be distinguished with designated letters. Mineral soil has four major horizons. The uppermost horizon, commonly called the surface soil, or topsoil, is the A horizon, the layer from which crop plants obtain water and nutrients. This soil layer may vary in thickness from several inches to several feet and is the layer most influenced by climate and most enriched by the accumulation of organic matter. The zone of greatest biological activity, this layer contains more microorganisms and is typically darker than underlying horizons. The subsurface E horizon, just below the A horizon, is known as the zone of leaching because in climates with high rainfall, plant nutrients leach downward from the E horizon farther into the soil profile.

Underlying the E horizon is the B horizon (see fig. 3.2), also called the zone of accumulation because it accumulates materials leached and transported (translocated) from the upper layers. Clay particles, oxides of iron and aluminum, calcium carbonate, calcium sulfate, and other salts from the E horizon are deposited in the B horizon, resulting in the formation of a soil layer that is usually more clayey than the topsoil. In young soil, where clay has had insufficient time to accumulate, no B horizon is present. As soil ages, increasing amounts of clay and other salts migrate and accumulate until the B horizon forms. The B horizon is usually lighter in color and contains fewer roots and microorganisms than the A horizon.

The layer of loose soil beneath the A, E, and B horizons, which is largely unaffected by accumulation of clay or organic matter is the C horizon. Little biological activity occurs there. When a soil develops in place, the C horizon is similar in chemical composition to the original parent materials from which the overlying A, E, and B horizons formed. The C horizon is much less affected than the upper horizons by physical, chemical, or biological agents. If the soil materials that form the C horizon developed in situ by weathering of bedrock, the material is called sedentary, or residual. In contrast, soil materials that have been moved to a new location by natural forces are said to have been transported. When water is the transporting agent, the surface soil is classified as alluvial (stream deposited), marine (sea deposited), or lacustrine (lake deposited). Wind-deposited surface soil is aeolian, and surface materials transported by glaciers are glacial.

The A, E, B, and C horizons, together with the unconsolidated rock fragments on top of the bedrock, are known as the regolith. Soil that forms in a hilly or mountainous terrain usually has a consolidated rock layer termed the R horizon below the four soil horizons. If the depth to consolidated rock is deeper than 6 to 7 feet, the soil is usually considered lacking an R horizon.

The soil around houses and condominium and apartment complexes has often been disturbed by construction and may not have the neat soil profile and distinct horizons shown in figure 3.2. The surface soil may not even be from the site. The best locations to see soil horizons and the results of the natural soil formation process are at road cuts or where new excavation is occurring.

Soil profiles and individual horizons may vary from a fraction of an inch to many feet deep. A typical natural soil profile extends to a depth of 3 to 6 feet. Soil profiles in many western states, such as California, are less developed than soil in more humid climates along the East Coast because less water percolates through western soil. As a result, many western soils contain more calcium, potash (potassium), phosphate, and other nutrient elements than do eastern soils.

Physical and Chemical Properties of Soil

A soil's physical and chemical properties affect plant growth and soil management. Important physical and chemical properties of soil include mineral content, texture, cation exchange capacity, bulk density, structure, porosity, organic matter content,

carbon-to-nitrogen ratio, color, depth, fertility, salt content, and pH.

Soil Minerals

Soil consists of particles with many sizes and shapes. Very coarse particles, such as gravel and stones, are inert or detrimental to plant cultivation. Soil mineral particles active in supporting plant growth are divided into three categories by size: sand, silt, and clay. Sand grains can be seen with the naked eye. Silt particles can be seen with magnification (a 10× hand lens). Clay particles cannot be seen without an electron microscope. Both the U.S. Department of Agriculture (USDA) and the International Soil Science Society have established standards for the size limits of sand, silt, and clay particles. The two systems do not agree exactly, but the key points for master gardeners are as follows:

The largest sand particles (2 mm diameter) are 1,000 times larger than the largest clay particles (less than 0.002 mm in diameter).

The smallest sand particle is 10 to 25 times larger than the largest clay particle, depending on the classification system.

Silt particles are intermediate in size.

Clay has thousands of times more surface area per gram than silt and almost a million times more surface area per gram than very coarse sand.

Table 3.1 illustrates that, for a fixed amount of soil, the total surface area increases as particle size decreases. Because many physical and chemical reactions in soil occur at the surfaces of mineral particles, clay minerals, on the basis of size alone, would be expected to have the greatest effect on soil mineral dynamics.

Soil mineral particles contain elements important to plant nutrition, such as potassium, calcium, sodium, iron, and magnesium, bound up within their crystalline structures. Sand and silt are composed mainly of primary minerals such as quartz, feldspar, mica, hornblende, and augite. The clay fraction contains secondary minerals (e.g., kaolinite, montmorillonite, and illite) that form as the primary minerals weather into secondary minerals; during this process, the elements that were bound within their crystalline structures are released, providing nutrients for absorption by plant roots.

Soil Texture

Soil texture—the relative proportions of sand, silt, and clay mineral particles—is one of the most important physical properties affecting plant growth because it determines tilth (fitness as a medium for growing plants) as well as nutrient- and water-holding capacities. A sandy, coarse-textured soil is often called a light soil, whereas a clay or fine-textured soil is referred to as a heavy soil. The terms

Table 3.1.

SIZES AND SURFACE AREA OF SOIL MINERAL PARTICLES

Soil type	Particle diameter (mm)		Surface area per gram
	USDA system	International Soil Science Society system	
very coarse sand	2.0–1.0	—	11
coarse sand	1.0–0.5	2.0–0.2	23
medium sand	0.5–0.25	—	45
fine sand	0.25–0.10	0.2–0.02	91
very fine sand	0.10–0.05	—	227
silt	0.05–0.002	0.02–0.002	454
clay	below 0.002	below 0.002	8,000,000

Source: Adapted from Foth 1978, p. 26.

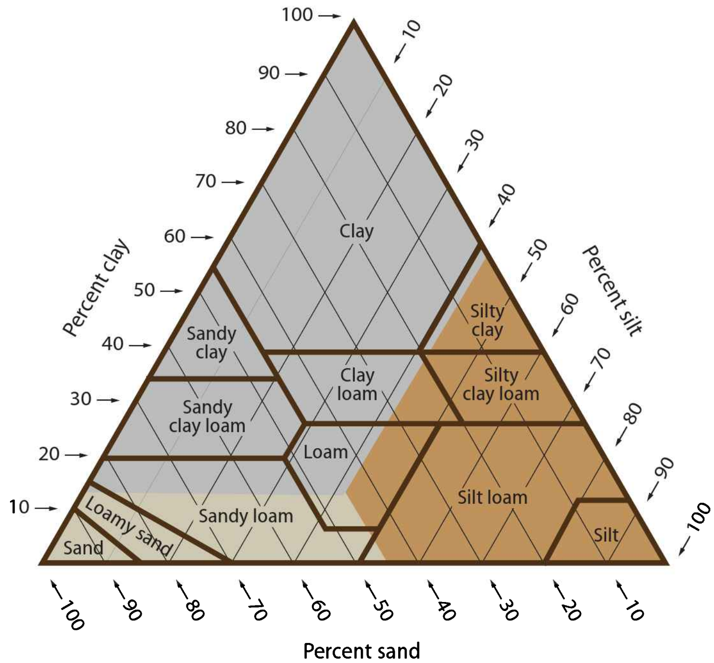
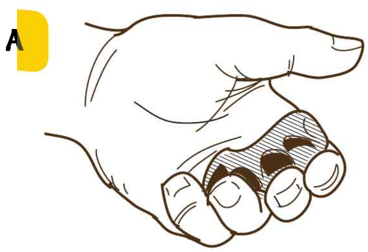


Figure 3.3

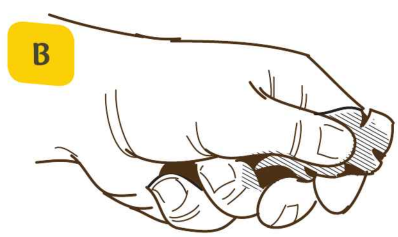
Soil textural classes. The chart shows the percentages of sand, silt, and clay in the 12 basic soil textural classes as defined by the USDA. Although organic matter may have a significant effect on a soil's physical properties, it is not considered in defining the soil's textural class. Each class is represented by an area in the textural triangle diagram. Thus, two soils may have the same texture but different particle size distributions. *Source:* After Wildman and Gowans 1978, p. 3.

Figure 3.4

Determining soil texture by the feel method. *Source:* After Wildman and Gowans 1978, p. 4, and Thien 1979.

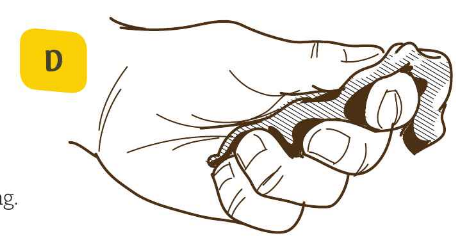


(A) Loamy sand, a coarse-textured soil. A cast will form when moist soil is squeezed in the hand. The cast cannot be handled without breaking; no ribbon can be formed.



(B) Loam, a medium-textured soil. A short ribbon can be formed with moist soil. The ribbon will split readily and will break away when less than 1 inch long. A moist cast of a loam soil will bear some handling.

(C) Clay loam, a medium-textured soil. A ribbon can be formed easily with moist soil. This ribbon is moderately strong but will break away when it is 1 to 2 inches long. A moist cast of a clay loam soil will bear moderate handling.



(D) Clay, a fine-textured soil. A strong ribbon can be formed with moist soil. The ribbon often will be more than 2 inches long. A moist cast will bear considerable handling.

reflect the relative ease of working the two soil types. Twelve basic soil textural classes are recognized in the USDA classification system. Figure 3.3 shows the names of the textural classes and the percentages of sand, silt, and clay associated with them.

Soil texture, as determined by its feel to the experienced gardener, is a good indicator of the soil's physical properties and behavior. The hands-on, experiential feel method shown in figure 3.4 can be used to deduce the majority of the basic soil textural classes identified in figure 3.3. With experience, the texture of a soil can be determined simply by rubbing moist soil between thumb and forefinger and noticing its characteristics: how it ribbons or is pushed out into a thin strip, how it hangs together, and how sticky, smooth, or gritty it is. Coarse and fine sand particles have a marked to moderate gritty feel and do not form cohesive balls. Silt feels smooth when dry and silky (slippery) when wet. Clay soil is sticky and plastic (able to be molded) when wet but hard and compact when dry, whereas silt imparts a smooth, silky feel. Sand makes soil feel gritty and rough.

The twelve soil textural classes can be grouped into three general texture categories: coarse (sandy soil), medium (loamy soil), and fine (clay soil):

coarse (sandy soil): sand, loamy sand

medium (loamy soil—moderately coarse, medium, moderately fine): sandy loam, loam, silt loam, silt, clay loam, sandy clay loam, silty clay loam

fine (clay soil): clay, sandy clay, silty clay

Effect of soil texture on plant growth

Soil texture affects many soil properties that in turn influence plant growth. For example, the coarser the soil texture, the faster the soil warms up in the spring. Thus, a sandy soil may give the gardener a few days' advantage in planting date because of better soil temperature conditions for germination and early seedling growth.

Water-holding and nutrient-storage capacities are determined largely by the distribution of particle sizes in the soil. Soil with finer texture (higher percentages of silt and clay) holds more water and nutrients than does coarser-textured soil (higher percentages of sand). Sandy soil has rapid water infiltration and good aeration but low water-holding and nutrient-storage capacities. Water may move too rapidly through a very sandy soil, with little water retained for plant use. If a soil contains an inadequate amount of sand, however, the soil's pores may be too small to support good drainage. Silt, with particles of intermediate size, has twice as much surface area per unit of volume as very fine sand. Compared with sand, silt has smaller pore spaces between particles; therefore, silty soil has a slower water infiltration rate but a higher water-holding capacity than sandy soil. Clay soil retains more water, has slower air and water movement, and holds more mineral nutrients than does coarser-textured soil. Soil composed chiefly of very fine clay particles has very limited movement of water and air because the individual pores are so small. Because water and air move more slowly in the pores of finer-textured soil, it can have pore sizes too small for suitable water percolation and aeration and thus can be difficult to manage.

Loam, sandy loam, and silt loam, ideally containing about 5 to 10% organic matter, are said to be the best soils for home garden cultivation because they provide a mixture of sand, silt, and clay, which retains sufficient water but also permits infiltration and percolation.

In the mineral soil typical throughout California, retention of plant nutrients is correlated with the amount and kind of clay in the soil. Clay is composed largely of secondary minerals, which are the weathering products of the primary minerals (quartz, feldspar, mica, hornblende, and augite) of which sand and silt are largely composed. Most of the clay particles formed from these secondary minerals are charged particles that carry net negative charges on their surfaces. Negatively charged clay particles naturally attract positively charged ions (cations), such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), ammonium (NH_4^+), aluminum (Al^{3+}), hydrogen (H^+), iron (Fe^{3+}), and sodium (Na^+), among others. Many of these cations are essential elements in plant nutrition. The attraction of ions or molecules to the surfaces of a solid, such as soil particles, is called adsorption. The adsorption of plant nutrient cations onto the surfaces of clay minerals balances the negative charges on their surfaces (fig. 3.5). Note that adsorption is different from absorption, which refers to the active or passive movement of ions or water into plant roots. Clay particles also repel negatively charged plant nutrient ions, such as nitrate (NO^{3-}) and sulfate (SO_4^{2-}). These

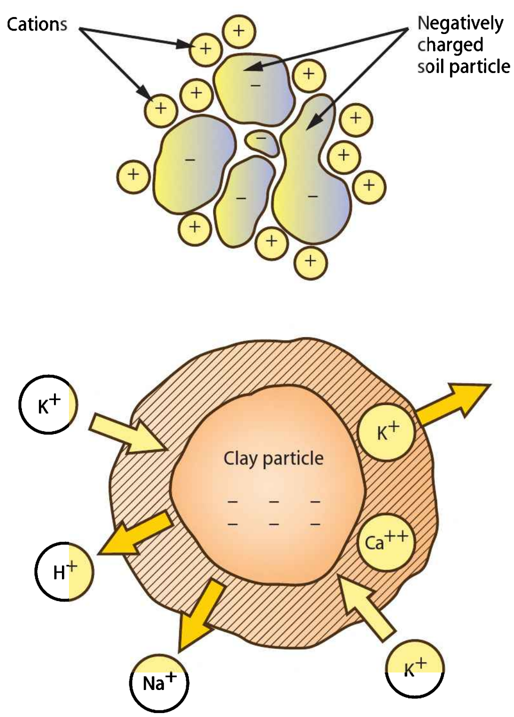


Figure 3.5

Schematic showing the exchange of cations between a negatively charged clay particle and the soil solution. Cations in the soil solution are available to be absorbed by plant roots. Cations are attracted to and held by negatively charged soil particles, while negatively charged ions (anions) are repelled and move with soil water. *Source:* After California Fertilizer Association 1998, p. 12.

important plant nutrients are available for plant use when they are dissolved in the water held in soil pores (the soil solution).

Cation exchange capacity

A constant exchange of plant nutrients takes place between clay minerals and the soil solution and between the soil solution and crop plants. Because clay minerals are active in these nutrient exchanges, they are major determiners of the chemical and physical properties of a given soil, and they largely determine how well plants will grow in that soil. Cations replace one another on the surfaces of clay minerals because of their affinity for the surfaces of the soil particles and because the soil maintains chemical equilibrium between the ions adsorbed onto soil surfaces and those in the soil solution. When cation exchange occurs, the cation released from the clay mineral into the soil solution becomes available for absorption by plant roots (see fig. 3.5).

The cation exchange capacity measures the amount of cations that can be adsorbed or held by a soil. It is measured in milliequivalents per 100 grams of soil. Mineral soils with a high cation exchange capacity are usually more fertile than those with a low exchange capacity because the former more effectively resist the loss of plant nutrient cations through the leaching process.

The amount and kind of clay in soil are critical factors in plant growth because clay's capacity to adsorb cations varies among kinds of clay. The types of clay that predominate in California have a higher exchange capacity than those typically found, for example, in the southeastern United States.

Clay minerals have a very high affinity for water. The negative charges on the clay minerals attract the positive charges on the hydrogen ions (H^+) in water (H_2O). Montmorillonite clay, a type found commonly in California, swells greatly when wetted and shrinks when dry, leaving wide cracks. An intermediate amount of clay in a soil (loamy texture) improves its capacity to hold water and plant nutrient ions because of the negative charges on clay minerals' surfaces and the large surface area associated with clay particles. A soil of clay particles has almost 100,000 times more surface area than a fine sandy soil of the same weight. This is an important concept because interactions with the surfaces of soil particles control retention and availability of water and most of the plant-available nutrients.

Bulk Density

A pound of cement and a pound of feathers both weigh the same, but the volume of each material needed to obtain that pound is vastly different. This property is density, the measure of weight per volume of a substance. A piece of solid quartz has a density of approximately 2.65 grams per cubic centimeter; that is, for every cubic centimeter of volume, a piece of solid quartz weighs approximately 2.65 grams.

When solid rock is crushed, some of the volume includes air with the rock; the density of the particles plus the air spaces is called bulk density. As rock materials are crushed more finely, the air occupying a given volume of material increases and the bulk density decreases. Bulk density provides a means of evaluating the amount of air or pore space in a given soil. Undisturbed sandy soil generally has a bulk density of about 1.6 grams per cubic centimeter, much lower than that of solid rock. Clay soil, which contains particles that are much smaller than sandy soil, has a bulk density of approximately 1.2 grams per cubic centimeter. Usually, as particle size decreases, bulk density decreases and total porosity increases, because fine-textured soil usually develops better structure (see below). Although bulk density is related to the amount of pore space in soil, bulk density does not indicate whether pores are large or small.

Soil Structure

Except for sand grains, soil particles typically do not exist as single particles but

rather coalesce into groups of particles known as aggregates, or peds. A soil's structure is the way in which aggregates are arranged. Plant growth is strongly influenced by soil structure because structure affects water movement, moisture availability to plants, fertility, aeration, porosity, heat transfer, bulk density, and mechanical resistance to root growth. Plants require air, water, and nutrients from the soil, and the air-water relationship depends largely on soil structure. A soil with good structure will have good water infiltration, drainage, aeration, and overall tilth.

A soil aggregate is a clump of soil particles held together in a unit so that it functions like a single large particle. Soil aggregates are naturally occurring structures that may vary from a fraction of an inch to several inches in diameter. Aggregates have characteristic shapes and sizes. Although for all practical purposes soil texture cannot be changed, soil structure can change within a single growing season, especially in the A horizon, because of weather and soil management practices. The structure of the subsoil horizons is less subject to change.

Soil structure development (aggregation) is enhanced as clay and organic matter (humus, plant and microbial exudates) increase because they act as binding agents, cementing individual particles into aggregates. Soil particles also aggregate because of physical forces, such as tilling operations and plant root growth, as well as climatic cycles such as wetting and drying and freezing and thawing. Climate influences rainfall, temperature, and the types of plants that will grow in a given soil, which in turn affect the soil's organic matter content. Calcium salts also contribute to aggregation, but sodium salts tend to disperse (deflocculate) soil particles, destroying soil structure.

Aggregation is very weak to nonexistent in sandy soil because it contains very little organic matter and clay. The structure of sandy soil is called single grained because individual particles (grains) act independently. Sandy soil drains well but does not retain much moisture, requiring more frequent irrigation and fertilization for plant roots to thrive.

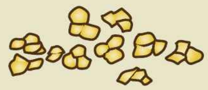
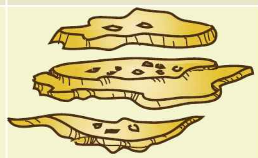
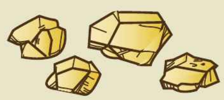
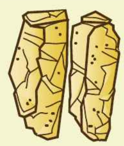
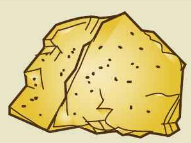
Table 3.2 describes the most common aggregate shapes: single grain, granular (crumbly), platy (flat), blocky (cubical), prismatic (columnar), and massive. Granular structure is usually found in surface horizons, provides an ideal environment for plant roots, and is particularly helpful for establishing plants from seeds or transplants. The larger pores between the granular aggregates are continuous, and roots may penetrate them with ease. Water drains readily through a granular soil, yet sufficient moisture is retained in the aggregates to supply root needs. The presence of clay or organic matter can promote porous, rounded granules in medium-textured soil, such as loam.

When the particles are arranged around a vertical axis bounded by relatively flat vertical surfaces, the structure is prismatic (prism-like, or columnar). Prismatic, or blocky, structures most often occur as a result of shrinking and cracking of clay loam and clay soil layers when they dry. The large cracks that are visible at the surface of dry clay soil may extend to 3 feet or deeper. The elongated chunks of soil between these vertical cracks are called prisms. The lower portions of the prisms often have horizontal cracks intersecting the vertical ones so that a more or less equidimensional blocky structure results. Prismatic, or blocky, aggregates may vary considerably in size but are always larger than granular aggregates. The aggregates swell when wet and may fit together so tightly that water drains through them rather slowly. Plant roots may follow cracks downward but do not usually penetrate to the centers of prismatic or blocky aggregates, so roots may not have access to water and nutrients contained within the aggregates.

Platy structure refers to thin, horizontal layers of soil stacked on top of one

Table 3.2.

PRIMARY TYPES OF SOIL AGGREGATES

Aggregate type*	Shape	Description	Common location in soil
single grain		usually individual sand grains not held together by organic matter or clay	sandy or loamy textured soils
granular		porous granules held together by organic matter and some clay	A horizons
platy		aggregates that have a thin vertical dimension compared to the lateral dimension	compacted layers
blocky		roughly equidimensional peds; usually higher in clay than other structural aggregates	B horizons with clay; common in subsoils in humid regions
prismatic		structural aggregates that have a much greater vertical than lateral dimension	B horizons; common in subsoils in arid regions
massive		no definite structure or shape; usually hard	C horizons and compacted, transported materials

Source: Adapted from Balge 1993.

Note: *The size of aggregates can be coarse (large), medium, or fine (small); the degree of expression can be strong, moderate, or weak. The type, size, and definition of aggregates found in a particular soil vary with the soil texture, composition, depth, management, and mode of formation.

another, which can occur when silty soil is deposited in thin layers by stream overflow. The discontinuities caused by this minute layering may interrupt the movement of water, air, and roots into the soil. Artificial platy structure may be caused by repeated compression of soil in trafficked areas and roadways.

Many medium-textured soils in California do not have well-defined structural aggregates because their organic matter content is much lower than that of soil in more temperate regions. If there is a lack of structure and particles are bound together in a solid mass, soil is said to have a massive structure. This soil may still provide a favorable root environment if it is open and porous, but if it is dense and compact, root growth will be restricted, as will water penetration and aeration.

Soil management practices can improve, maintain, or destroy soil structure. Soil structure takes years to form but can be broken down rapidly through mismanagement, improper tillage, or intensive cultivation. Working, walking, or driving on soil when it is wet leads to compaction and loss of structure. Soil must be somewhat moist to work, but if a

soil is worked immediately after wetting, soil structure can be damaged. Soil should be allowed to drain for at least 1 to 2 days after watering before it is mechanically worked, the length of time being greater in soil with high clay content.

A soil profile may have a single type of aggregation, but each horizon frequently has a characteristic structural pattern (see table 3.2) determined largely by the degree of soil weathering, which is a function of the five primary factors that govern the soil formation process (the CLORPT equation; see “Soil Formation,” above).

Soil Porosity

When soil solids (minerals and organic matter) are packed tightly together, tiny voids (pores) still exist between the solids. Pores are often connected, and the connected pore space conveys oxygen, water, and dissolved mineral nutrients and provides space in which roots grow. Pores not filled with water are filled with air. In moist soil suitable for plant growth, the pore space is occupied about equally by air and water (see fig. 3.1). Usually the larger pores (macropores) are filled with air because water drains from them by the force of gravity (fig. 3.6). Small pores (micropores) are responsible primarily for water storage. Soil with good pore structure has a balance of macropores and micropores that ensures adequate water movement, water storage, space for plant root growth, and aeration.

Plant root and most microbial respiration consume oxygen and produce carbon dioxide. Oxygen in the soil air is essential for root respiration, other root functions, and the metabolism of soil organisms. Air-filled pores provide a pathway for soil to take in oxygen and release carbon dioxide. When soil is overwatered, all or most of the pore spaces fill with water. Because oxygen is not readily available in waterlogged soil, plant roots cannot respire efficiently; they become oxygen starved and cannot make efficient use of available nutrients. Suffocating roots contributes to poor growth. Seeds sown in waterlogged soil may fail to germinate because oxygen is inadequate for respiration.

Nitrogen becomes less available as soil becomes more waterlogged. Nitrogen that would normally be available to plants is converted to forms that plant roots cannot absorb when the supply of oxygen is inadequate in root zone pores. Keeping soil pores filled with a mixture of air and water is very important for plant growth. Other chemical properties and reactions important to plants may be adversely affected when soil oxygen levels are severely limited.

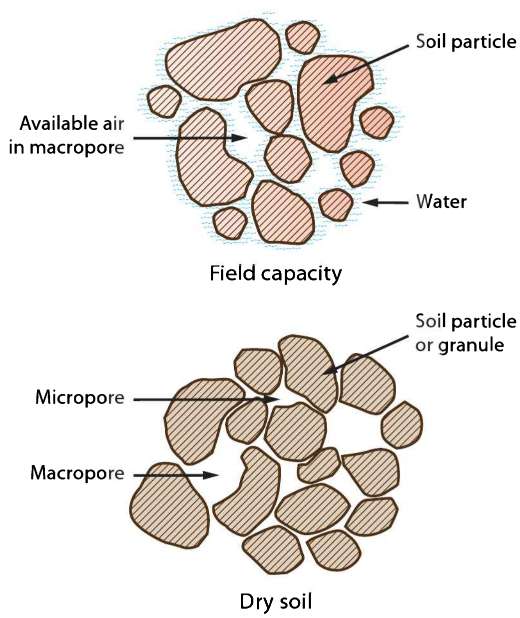


Figure 3.6

Soil texture and structure influence the total porosity and pore configuration. Total porosity increases with decreasing particle size, but pore size decreases as mineral particle size decreases. Thus, a sandy soil (high bulk density, low porosity) drains better than a clay soil (high porosity, low bulk density) because the clay soil has much smaller pores than the sandy soil. The smaller pores are less able to transmit water and gases. Both total porosity and pore arrangement determine water movement in soil and soil oxygen availability.

Soil Color

Soil color can be determined easily and is one of the most useful characteristics in soil classification and identification. Color is a function of the amount of organic matter, the original parent material, the degree and kind of weathering of the soil, the amount and type of salts present in the surface layer, and the aeration of the

soil. Although soil color does not have a direct influence on soil productivity, it often can provide information about the chemical makeup or drainage status of the soil. Organic matter tends to darken soil, which influences soil temperature. Dark soil is warmer than light soil, but it is not necessarily more fertile. The following generalizations can be made about soil of different colors.

Gray and brown soils form the largest group of California soil. They are moderately low in organic matter but include some of the state's most productive and fertile alluvial soil, the soil that forms from periodic flooding by streams and the accompanying deposition of soil materials. Nearly all soil on the floors of the Central Valley and the coastal valleys of California is alluvial, unlike the residual soil that forms in place from the underlying rocks in upland areas. The gray soil on the eastern side of the Central Valley formed from granitic alluvium and is coarse to medium textured. The brown soil on the western side of the Central Valley formed from sedimentary alluvium and is medium to fine textured.

Black soil is relatively high in organic matter, but the amount can vary from less than 5% (mineral soil) to more than 50% (peat and muck). In the Central Valley, black soil that has formed under poorly drained conditions is either peaty or clayey in texture, but with good management practices it can be highly productive for field and vegetable crops. In upland and coastal areas, black soil with strong granular structure formed under native grassland, on fine-textured parent materials, and in cool climates.

The color of older soil is generally red or yellow, which indicates that the soil is losing nutrients and other constituents. Red soil is generally old soil that has undergone intensive weathering. Often, the subsoil has restrictive claypans (a noticeable increase in clay) or hardpans (dense rocklike layers) that act as a barrier to root and water penetration. Water may accumulate above these layers, and roots may be injured because of poor aeration. Red soil is often deficient in nitrogen, phosphorus, zinc, and sulfur. Iron oxides usually contribute yellow and red colors to this soil. Intermittent poor aeration caused by poor drainage can create a rust-colored, mottled appearance.

White or light gray soils are usually sandy or calcareous (containing lime). Sandy soil may exhibit this color if it is highly leached. In calcareous soil of this color, iron deficiency may be a problem for orchard crops. In arid or poorly drained environments, white-colored salts, such as calcium carbonate, calcium sulfate, or sodium carbonate, can accumulate at the surface. Sodium salts cause organic matter to oxidize, turning it black, and they also cause aggregates to disperse.

Blue or blue-gray layers are usually found in poorly aerated subsoil where organic matter is decomposing anaerobically (without air). This soil can have a sewer-like odor because it contains gases and dissolved matter toxic to plant roots. Extensive aeration can restore this soil to a condition suitable for plant growth.

Soil Depth

Soil depth refers to the vertical distance from the soil surface to a layer that stops the downward growth of plant roots and water penetration. The barrier layer may be rock, gravel, a claypan, a hardpan, or a partially cemented layer of soil. A deep soil provides more water and nutrients to plants than a shallow soil. Soil depth can be described as follows:

very shallow: less than 10 inches
shallow: 10 to 20 inches
moderately deep: 20 to 36 inches
deep: 36 to 60 inches
very deep: deeper than 60 inches

Soil pH

The term *pH* describes the relative acidity or alkalinity of a solution. An acidic solution (which has a low number of hydrogen ions) can remove hydrogen ions from an alkaline solution (which has a high num-

ber of hydrogen ions) to form a salt. The pH is the relative concentration of hydrogen ions in a solution. Therefore, an acidic solution, with low hydrogen, has a low pH value, and an alkaline solution, with high hydrogen, has a high pH value. (It is convenient to think of pH as a measure of alkalinity: the higher the value, the more alkaline the solution.) The pH scale ranges from 1 to 14, with 1 being highly acidic and 14 highly alkaline, or basic. At pH 7.0 alkalinity and acidity are balanced, and the pH may be called neutral. Like the scale for measuring earthquakes, the pH scale is logarithmic, not linear: a pH of 5.0 is 10 times more acidic than a pH of 6.0 and 100 times more acidic than a pH of 7.0.

Most crops do best when the pH of the soil is slightly acidic to neutral (pH 5.5–7.5). Soil in California typically ranges from pH 5 to 8.5, but a pH near neutral or slightly alkaline is most common. Soil pH can be easily measured with relatively inexpensive and reliable kits sold at garden centers. For details on adjusting soil pH, see the discussion on amending soil chemical problems in the section "Managing and Amending Soil Physical and Chemical Properties," below.

Soil Salts and Salinity

Chemically speaking, a salt is the neutral product of the reaction between an acid and a base. Salts contain a balance of cations (positively charged ions) and anions (negatively charged ions). Soluble salts are minerals dissolved in water. In moist climates they are naturally washed out (leached) by rainfall, but in arid and Mediterranean climates they naturally accumulate as water evaporates and leaves them behind. Salts are added to soil naturally through deposition of dust and precipitation. Fertilizers contribute plant-essential nutrients in the form of soluble salt compounds. Irrigation water also contains soluble salts; the salt concentration in water varies throughout the state.

As the salts in the soil become concentrated, it becomes more difficult for plants to take up water, and too much salinity can damage susceptible plants directly. The salt concentration in soil is measured as electrical conductivity (EC) in units of decisiemens per meter (dS/m). An EC level of 2.0 dS/m or greater can significantly reduce growth of salt-sensitive plants, but many plants tolerate an EC level of about 4.0 dS/m. Levels of two to four times this amount are usually necessary before easily diagnosed foliar symptoms (leaf burn or scorch and leaf drop) are expressed. Measuring salinity, or electrical conductivity, can be cheaply accomplished with a portable EC meter.

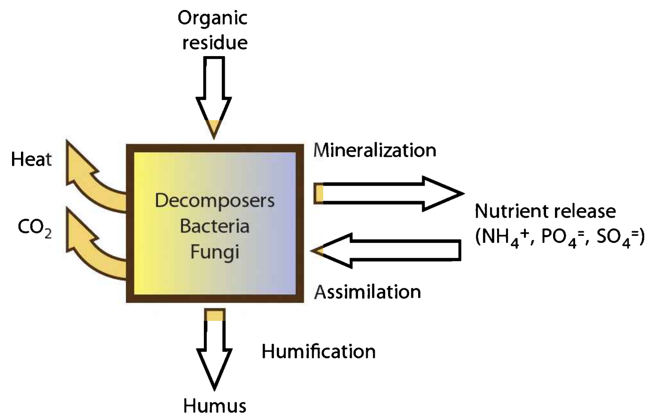
A saline soil has high levels of soluble salts and usually a high pH in the root zone. Saline soil can develop in the semiarid climates of California because evaporation of water vapor from the soil surface is more prevalent than leaching, and salts dissolved in the water accumulate in the root zone. Saline soil may develop surface incrustations of whitish-looking soluble salts that are brought to the surface as water vapor evaporates. When a soil has a high concentration of soluble salts, plant roots have difficulty absorbing water molecules because the molecules are tightly held by salt ions (osmotic stress). Plants can become dehydrated and wilted, grow slowly, and in extreme cases, die. Many ornamental, fruit, and vegetable plants are sensitive to salinity. Saline soil should be irrigated with excess water, more than is required by the plants, to wash excess salts from the root zone.

Other western soil, known as sodic soil, has pH that is too high (greater than 8.5) because of an excessive accumulation of sodium (Na^+) without an adequate concentration of other salts. High concentrations of sodium are toxic to plants and can disperse soil particles, which destroys soil structure and results in poor water and air infiltration. Some soil is both sodic and saline.

For details on managing soil salinity and sodium, see the discussion in "Manag-

Figure 3.7

Decomposition of soil organic matter releases nutrients, particularly nitrogen, phosphorus, and sulfur, which are taken up by plant roots. Humus improves soil fertility and water retention and infiltration rates. *Source:* After Chaney et al. 1992, p. 4.



ing and Amending Soil Physical and Chemical Properties," below.

Soil Organic Fraction

The organic fraction of the soil is the solid phase that originates from living organisms, unlike the mineral fraction, which originates from nonliving rocks. Soil organic matter, consisting primarily of carbon (50–55%) and nitrogen (7–8%), is a reservoir of plant nutrient elements. It includes living organisms (fungi, bacteria, earthworms, etc.) and organic matter derived from plant and animal residues in various stages of decomposition. Soil bacteria and fungi that use plant and animal residues as their source of food and nutrition constantly decompose soil organic matter. The residue left from decomposition of soil organic matter derived from plant and animal material is called humus (fig. 3.7).

Soil organic matter content varies according to climate and soil type. Organic matter constitutes less than 1% of the well-drained soil of warm, dry regions; 1 to 10% of the mineral soil of cool, moist regions; and 5 to more than 50% of poorly drained valley soil originating in swamps. Frequent tillage and crop removal tend to reduce the natural organic matter content of soil.

Humus

Even though mineral soil contains relatively small amounts of organic matter, soil chemical and physical properties are mainly functions of humus and clay minerals. Like clay minerals, soil humus has negative charges on its surface and attracts water and plant nutrient cations, such as ammonium (NH_4^+), calcium, (Ca^{2+}), magnesium (Mg^{2+}), hydrogen (H^+), and potassium (K^+). Humus increases a soil's cation exchange capacity and improves soil fertility because the adsorbed cations remain available in the root zone for use by plants. There is a constant exchange of nutrients between soil solids (clay minerals and humus) and the soil solution and between the soil solution and crop plants (see fig. 3.5). Humus also aids in the formation of granular aggregates, improving soil structure (see table 3.2). Humus tends to be brown or very dark brown, and soil rich in organic matter takes on this darker hue. The predominant components of humus are humic and fulvic acids.

Earthworms, saprophytes, and other beneficial soil organisms

Earthworms and saprophytic soil organisms contribute to soil fertility. Most of these creatures live near the soil surface in the root zone of crop plants. A gram of soil may contain as many as 4 billion bacteria, 1 million fungi, 20 million actinomycetes, and 300,000 algae. Some of these soil organisms are visible to the naked eye, whereas others are microscopic. Although most are beneficial to crop plants, a few destructive plant pathogens use garden crops as their food source.

Earthworms are segmented worms that are part of the beneficial soil macrofauna visible to the naked eye. As earthworms feed on plant residues and move about, they stir and aerate the soil by leaving holes in it, improving soil structure. After they feed and digest decaying organic plant residues, their excreta and casts are

very high in plant-available nutrients, such as phosphates (PO_4^{3-}, HPO_4^{2-}), potassium (K^+), nitrate nitrogen (NO_3^-), and exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}).

Soil saprophytes are beneficial soil microorganisms (bacteria and fungi) that act as decomposers and recyclers, feeding on decaying plant residues left in the soil after harvest, decomposing them, and recycling them into beneficial products such as available nutrients and humus. Saprophytes release plant nutrient elements in simple mineral forms—formerly bound up in complex organic molecules in soil organic matter—that then become available for uptake by plants.

Beneficial saprophytic soil bacteria and fungi have important roles in development and maintenance of soil fertility and structure as well as the recycling of organic waste (see fig. 3.7). As they feed on dead and decaying plant residues from the previous crop, soil saprophytes use enzymes to break down the residues and metabolize them into mineral forms of nitrogen (NH_4^+), sulfur (SO_4^{2-}), and phosphorus (PO_4^{3-}) that a growing plant can use and absorb through its roots. Because plant roots cannot absorb nutrients in complex organic forms, the saprophytic soil organisms perform an invaluable recycling function when they decompose plant residues left in the soil into simpler mineral forms needed by plants. In this way, soil organic matter serves as a slow-release fertilizer that provides a continual supply of inorganic nitrogen, phosphorus, sulfur, and other nutrients to garden plants.

As they feed on organic residues, saprophytes excrete gummy substances that bind and stabilize aggregates, improving soil structure. Soil organic matter promotes a crumb-like granular soil structure. Improved aggregation is coupled with better pore structure and a more even distribution of large and small pores, which improves water-holding capacity, water infiltration rate, and aeration. Saprophytic bacteria and fungi also release carbon dioxide (CO_2) into the soil atmosphere (see fig. 3.7). Carbon dioxide can move directly from the soil atmosphere to the air or can combine with water (H_2O) to form carbonic acid (H_2CO_3). Together with other acids, carbonic acid facilitates weathering of soil minerals, which increases nutrient availability to plants by releasing ions previously bound within the structure of the soil minerals.

Not all beneficial soil bacteria and fungi are saprophytes. Instead of feeding on decaying organic matter, other groups of beneficial fungi and bacteria form associations with plant roots. Some groups of soil bacteria and fungi can fix atmospheric nitrogen (N_2), which means that they can convert it into ammonia (NH_3) or ammonium ions (NH_4^+). Crop plants cannot use atmospheric nitrogen directly, but they can absorb ammonium fixed by beneficial microbes. For example, *Rhizobia* spp. bacteria that live in association with the roots of legume plants inhabit nodules in the roots and provide nitrogen to the legume plants by capturing atmospheric nitrogen and converting it to ammonium. Other species of beneficial bacteria convert soil ammonium into nitrites (NO_2^-) and eventually nitrates (NO_3^-), which plants can also absorb.

Mycorrhizae

More than 75% of all terrestrial plants, including the crops in your garden, form associations between their roots and soil fungi. These associations, called mycorrhizae, are generally beneficial to both the crop plant and the fungus. The plant roots provide carbon-containing compounds that serve as a food source for the fungi, and the fungi improve the roots' absorption of phosphorus and other plant nutrients. Mycorrhizae are also common in woody plants. They are ubiquitous in garden settings; introducing commercially produced inoculum is not likely to be beneficial.

Many beneficial soil microorganisms (bacteria, fungi, and actinomycetes) that are associated with plant roots synthesize plant hormones (auxins, gibberellins, cyto-

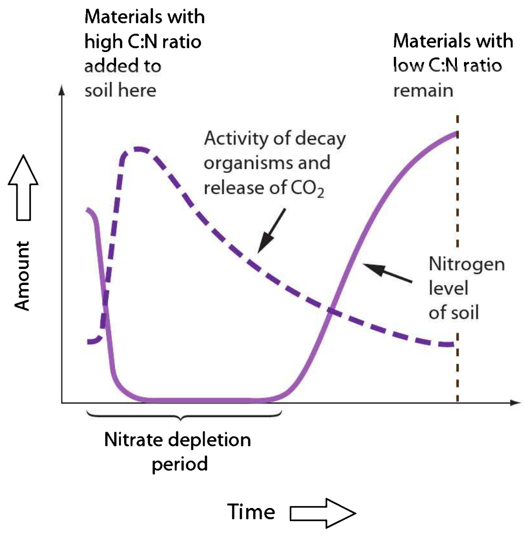


Figure 3.8

The cyclical relationship between activities of decomposers and nitrate nitrogen levels in soils when organic residues with a high carbon-to-nitrogen ratio are incorporated into the soil.

kinins, ethylene, and abscisic acid) and have positive effects on plant growth and development. Rhizobacteria, such as *Rhizobia* spp. and mycorrhizal fungi, synthesize and release plant hormones that are absorbed by plant roots. The study of microbially derived plant hormones and their regulatory effects on plant growth and development is an active area of research in soil science.

Effect of organic matter on soil fertility: The carbon-to-nitrogen ratio

Because organic matter is known to improve soil fertility, it is often added to garden soil in large amounts. However, adding organic matter to garden soil may not improve soil fertility immediately. The cyclical relationship between the activities of decomposers (saprophytic fungi and bacteria) in the soil and the availability of nitrate nitrogen (NO_3^-) to plants is illustrated in figure 3.8. The ratio of carbon to nitrogen (C:N) is the amount of carbon compared with the amount of nitrogen present in soil organic matter. In most productive soils, this ratio is fairly constant, varying from about 10:1 to 12:1, which means that the carbon level is about 10 to 12 times greater than the nitrogen level.

Soil microorganisms need both carbon and nitrogen to grow. Lack of available carbon in the soil often limits microbial activity. What happens when carbon-rich organic matter, such as leaf litter, bark, straw (C:N = 80:1), or sawdust (C:N = 500:1) (table 3.3), is added to the soil or when the plant residues from a previous crop are left to decay in the soil? The decomposers in the soil receive a bonanza food supply that contains a lot of carbon but relatively little nitrogen. As the populations and activities of decomposers increase, they consume carbon and nitrogen, depleting the limited nitrogen supply, until nitrogen becomes a limiting factor in plant growth. In this process, called immobilization, the microbes compete directly with the garden plants for inorganic ammonium (NH_4^+) and nitrate nitrogen (NO_3^-). Decomposers feeding on organic matter with a high C:N ratio (greater than 25:1) incorporate the nitrogen in the organic material into their own cellular tissues and also rob the soil of inorganic nitrogen, so that the levels of soil nitrogen available to plants are reduced (see fig. 3.8).

Therefore, it is best to add an inorganic nitrogen fertilizer to the soil when undecomposed organic residues with a high C:N ratio are incorporated just before planting or during plant growth. The length of the time that nitrogen may be limited depends on the amounts and types of organic residues added to the soil. As the process of humus formation nears completion, many of the decomposers die and their activities decrease. Other soil bacteria feed on the dead decomposers and convert organic nitrogen in the dead cells into nitrate nitrogen, supplying nitrogen in an inorganic form that garden plants can use. In time, the soil will become more fertile and more productive because nitrogen availability to plants increases. Soil structure may improve because of the synthesis of humus.

When organic matter with a high C:N ratio is applied to the soil surface as a mulch (which means that it is not incorporated into the soil), nitrogen deficiency (see fig. 3.8) is usually not a problem because the mulch decomposes very slowly. Organic mulches can also reduce weeds and retain soil moisture.

What happens when nitrogen-rich organic residues with a low C:N ratio (less than 25:1) are incorporated into the soil? They decompose rapidly. Nitrogen levels do not become limiting, and the decomposition process releases excess nitrogen from organic matter in inorganic forms (both ammonium and nitrate) that garden plants can absorb. A period of nitrogen unavailability does not occur.

Rapid Backyard Composting

Composting is a process in which organic substances are reduced from large volumes of rapidly decomposable materials to small volumes of materials that continue to decompose slowly. In this process, carbon is lost as carbon dioxide, and the ratio of carbon to other elements is brought into balance, avoiding temporary immobilization of nutrients discussed above. The end products of decomposition of plant materials are water, carbon dioxide, and minerals important to plant nutrition and soil fertility. One of the many benefits of adding composted waste to the soil is that the nutrients in compost are released slowly to the soil and are then available for use by plants. The length of time it takes fresh organic matter to become compost depends on the composition and condition of the materials in the pile and the management practices of the gardener. The general rule of thumb is that the pile must be warm, aerated, and moist, and it should comprise nearly equal proportions of chopped, fresh green material (grass clippings, kitchen scraps) and dry brown materials (straw, paper, dry leaves) (see table 3.3).

Table 3.3.

CARBON-TO-NITROGEN (C:N) RATIO OF GREEN AND BROWN COMPOSTING INGREDIENTS

Ingredient	C:N ratio
Greens	
alfalfa hay	12:1
food wastes	15:1
grass clippings	19:1
rotted manures	20:1
fruit wastes	35:1
Browns	
cornstalks	60:1
leaves	60:1
straw	80:1
sawdust	500:1
wood	700:1

The traditional method of composting was to pile organic materials and let them stand for about a year, at which time the materials would be ready for use. The main advantage of this method is that little working time or effort is required from the composter. Disadvantages are that space is used for an entire year; some nutrients might leach out because of exposure to rainfall; disease-producing organisms, some weeds, weed seeds, and insects are not controlled; and odors may develop. A new backyard method addresses some problems associated with traditional composting. Backyard compost can be made, on average, in 4 to 6 weeks with this process. With extra effort, the backyard composting process can take as little as 14 days. Several factors and concepts are essential to success in rapid backyard composting. All are important; there is no significance to the order of presentation here.

Size of Materials

Material will compost best if pieces are 1/2 to 1 1/2 inches in size. Soft, succulent tissues need not be chopped into very small pieces because they decompose rapidly. Harder, or woodier, tissues must be divided into small pieces with a chopper or shredder to decompose rapidly. Most grinders chop herbaceous materials too finely for good composting. Chopping material with a sharp shovel is effective. When plants are pruned, cut the material into small pieces with the pruning shears. It takes a little effort but the results (and the exer-

cise!) are worthwhile. For the composting process to work most effectively, the material to be composted should have a C:N ratio of 30:1. This cannot be measured easily, but experience has shown that mixing equal volumes of green plant material and naturally brown plant material will give a C:N ratio of about 30:1 (see table 3.3). Dry brown plant materials include wood chips, dried leaves, dried grass, straw, and prunings. Green materials are fresh and moist, and include grass cuttings and food scraps (avoid meats, fats, and grease), weeds, and manures (see the comments about weeds at the end of this section). Contrary to popular opinion, eucalyptus and oleander can go into a compost pile; decomposition will detoxify them. Greens may be easier to find in fall and early spring. Paper bags, cardboard egg cartons, cereal boxes, and paper can be used for browns, but they must be finely chopped or shredded. Cartons should be washed before adding to the compost pile. Milk cartons can be composted. Newspapers can be used if shredded and thoroughly mixed with plant tissues to prevent matting, which excludes the oxygen necessary for rapid decomposition. Some greens, such as grass clippings, also may mat if dry materials are not used to separate them.

Size and Volume of the Compost Pile

An optimal compost pile is about 3 to 4 feet square. Larger piles tend to hold moisture better and decompose faster. Equal amounts of browns and greens should be placed in a heap or bin, and food scraps should always be covered with other composting materials. The pile should be soaked with water to create uniform dampness (as damp as a wrung-out sponge) and covered with a tarp or other material to retain moisture and to prevent oversoaking from rain.

Heat accelerates composting and is supplied by the respiration of microorganisms as they break down the organic materials. To conserve heat, a minimum volume of material is essential: a pile at least 3 by 3 by 3 feet is recommended. Rapid composting will not occur in smaller piles. Bins promote rapid composting because they retain heat better than do open piles; in addition, bins are neater. High temperatures favor the microorganisms that are the most rapid decomposers. These microorganisms function at about 160°F, and a good pile will maintain itself initially at about that temperature. The temperature then gradually tapers off. In the Los Angeles County Cooperative Extension Backyard Composter Program, piles typically reach temperatures of 135° to 150°F. The higher temperatures are common for the first week and can even extend into the second week, but after that, temperatures drop to about 130°F and lower. By the sixth week, temperatures are typically about 90°F. A composting thermometer (about 20 in long) can be helpful for measuring temperature inside the pile. These thermometers can be purchased from gardening catalogs or local nurseries and home centers. Insects may be attracted to the pile, but if they lay their eggs in the compost, the heat will destroy them.

Turning the Pile

Turn the compost to prevent overheating. If the compost gets much warmer than 160°F, the microorganisms will be killed, the pile will cool, and the whole process will have to be started from the beginning. Turning the pile also aerates it, which is necessary to keep the most active decomposers functioning. Turn the pile so that material on the outside is moved to the center, allowing all the material to reach optimal temperature at various times. Because of heat loss around the margins, only the central portion of the pile is at the optimal temperature. It is desirable to have two bins so the material can be turned from one into the other. Bins that can be moved section by section and bins with removable slats in the front make the turning process easier (fig. 3.9). Bins with

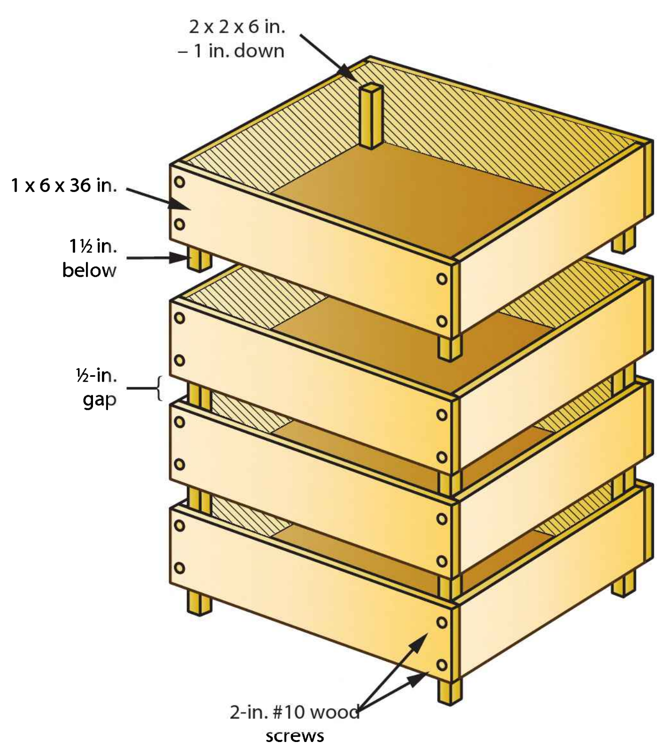
covers retain heat better than do those without them. Once the decomposition process starts, the pile becomes smaller and, because the bin is no longer full, some heat is lost at the top. Heat loss can be prevented by placing a piece of polyethylene plastic directly on the top of the turned compost and tucking it in around the edges. Longer intervals between turning lengthens the time to compost completion. Turning the pile every 3 to 10 days results in finished compost in 4 to 6 weeks. If the pile is turned every other day, composting may take about 3 weeks. If it is turned every day, composting may take as little as 2 weeks.

Adding Water

If greens and browns are mixed properly, only water should be added to a compost pile. Nothing else must be added to promote decomposition. The microorganisms active in the decomposition process are ubiquitous, and their populations grow rapidly in any compost pile. Monitoring the moisture content of the pile is essential because piles will dry out because of the high temperatures they attain. Composting works best if the moisture content of materials is about 50%, about the moisture content of a wrung-out sponge. Too much moisture makes a soggy mass, and decomposition will be slow and smelly. Not enough moisture causes decomposition to be very slow or not to occur at all. When turning the pile, moisten each layer of compost using a spray nozzle for uniform coverage. Once a pile is started, add only water. Do not add new materials, because the organic materials need time to break down, and added material must start the process anew, lengthening decomposition time for the whole pile. Excess materials should be kept as dry as possible during storage until a new pile is started. Moist materials start to decompose and will not be effective in the next compost pile.

Figure 3.9

Home-built compost box designed by the Backyard Composter Program, Los Angeles County Common Ground Garden Program, UC Cooperative Extension.



Maintenance

If constructed correctly, a compost pile will heat to high temperatures within 24 to 48 hours. If it does not, the pile is too wet or too dry or there is not enough green material (or nitrogen) present. If the pile is too wet, the material should be spread out to dry. If it is too dry, add moisture. If neither of these is the problem, then the nitrogen level is too low (high C:N ratio), which can be corrected by adding more greens or nitrogen (N) fertilizer. If necessary, add nitrogen fertilizer at the rate of 1 pound nitrogen for every 10 cubic feet (about 200 lb) of material, the equivalent of 5 pounds ammonium sulfate (21% N) or 3 pounds ammonium nitrate (33% N). It is essential the fertilizer be mixed in the compost pile.

If the C:N ratio is less than 30:1, the organic matter decomposes very rapidly

but nitrogen can be given off as ammonia. The odor of ammonia in or around a composting pile indicates that valuable nitrogen is being lost into the air. Adding sawdust or another material with a high C:N ratio to the pile counteracts the nitrogen loss because the excess carbon will tie up (immobilize) nitrogen.

Rapid decomposition can be detected by a relatively pleasant odor, by the heat produced (visible as water vapor given off during the turning of the pile), by a reduction of volume, and by the change in color of the materials to dark brown. As composting nears completion, the temperature drops and, finally, little or no heat is produced. Within 6 weeks, temperatures typically drop off to 90°F. Although the compost is then ready to use, the compost should remain in the pile to cure for up to 2 weeks. If, in the preparation of the compost, the material was not chopped into small pieces, screening the material through 1-inch-mesh chicken wire will hold back larger pieces, which can be added to the next pile, where they eventually will decompose. Table 3.4 mentions some possible causes of and solutions to common composting problems.

Materials Not to Be Composted

The following materials should NOT be added to a compost pile:

Soil. Soil adds nothing but weight to a compost pile and will discourage the turning of the pile, which is necessary for rapid composting.

Ashes from a stove or fireplace. Because most soil in California has a basic pH and wood ashes are basic, they should not be added to a compost pile or to the soil. Wood ashes do not decompose.

Meat, fat, or cooked fruits and vegetables. Raw fruits and vegetables, peelings, and eggshells are perfect for the compost pile, but many cooked foods, meat, and fat should not be added.

Manure from meat-eating animals as well as human waste. Manure from carnivorous animals, such as dogs and cats, could contain disease-producing organisms that might infect humans. Because the rapid composting process may not kill these organisms, such manures should not be used. Manures from herbivorous animals, such as rabbits, goats, cattle, horses, elephants, or fowl, can be used, but such manures are not essential for making compost. You can make compost without adding any manure to the pile.

Certain seed-bearing weeds. Most weeds and weed seeds are killed by the high temperatures of the pile, but not all. For example, oxalis bulbs, seed of burclover, some amaranthus seeds, and seed of cheeseweed are not killed. Exclude seed-bearing weeds from the pile to reduce the potential spread of weeds.

Plant materials that look diseased. Performed correctly, rapid composting kills most, but not all, organisms that cause plant disease; it does not inactivate heat-resistant viruses, such as tobacco mosaic virus. Examine greens for evidence of viral diseases and exclude them from the pile.

Alternatives for Recycling Kitchen Organic Waste

Some people have success adding fresh kitchen garbage, including fruit and vegetable wastes, to the compost pile. Other people have reported that their kitchen wastes tend to turn slimy and degrade slowly and that animals attracted to the pile scatter the waste around the yard and burrow into the pile. One recycling alternative to composting kitchen organic waste is burying the waste in the garden soil to a depth of 2 to 3 feet with a posthole digger. Another option is vermiculture.

Vermiculture

The practice of raising redworms in boxes and feeding them kitchen wastes is known as vermiculture. Because worms eat their own weight each day, a pound of worms eat a pound of food every day. Native to Egypt, redworms are often known as manure worms. It may be necessary to purchase worms to get the box started.

Many gardeners are interested in vermiculture for its recycling attributes and for the worm castings, which provide a high-quality soil amendment with some fertilizer effects.

Vermiculture requires a box with a hinged lid (about 4 ft long by 2 ft wide) and 3/4-inch holes drilled on all sides. The box should be covered with screen and placed on a stand so air can circulate under and around it. Bedding for the worms can be well-shredded newspaper or any loose organic matter. The worms must be kept moist in a cool, shady place and should be fed daily or every few days with kitchen wastes. After the worms have turned all the bedding and food into rich castings, the castings should be pushed to one side of the box and fresh bedding and food added to the empty side. In a few days to a week, the worms will have moved into the new area to feed, and the castings can be used in the garden. A screen with large openings can also be used to divide the box into two compartments.

Soil Water

Soil water occupies the pore space not occupied by soil air (see fig. 3.1). Soil water is the solvent in which plant mineral nutrients are dissolved to form the soil solution, and it transports these nutrients to plant roots, where they are taken up to meet plants' nutritional needs for growth and development. Many other minerals and compounds are also dissolved in the soil solution.

How water moves and is held in soil is a complex subject that requires an understanding of physics and chemistry. Only the most basic concepts are introduced here. Suppose you add a cup of water to your favorite house plant or vegetable in the garden. The water enters the pore spaces between the soil particles. Does it just move downward? Do the plant roots absorb the whole cup of water over the next few days? Is all the water available to plant roots? The answer is that not all the

Table 3.4.

TROUBLESHOOTING COMPOSTING PROBLEMS

Problem	Possible causes	Solution
rotten odor	not enough air; excess moisture (anaerobic conditions)	turn pile; add dry, porous materials such as dry leaves, sawdust, wood chips, or straw
	compaction	turn pile or make it smaller
ammonia odor	excess greens (nitrogen)	add browns (carbon), such as dry leaves, wood chips, or straw
low pile temperature	pile too small	enlarge pile or insulate sides
	insufficient moisture	add water while turning pile or cover top
	poor aeration	turn pile
	lack of greens (nitrogen)	mix in greens, such as grass clippings, manure, or food scraps
	cold weather	increase pile size or insulate pile with an extra layer of material such as straw
high pile temperature (> 140°F)	pile too large	reduce pile size
	insufficient ventilation	turn pile
pests (insects, rats, raccoons)	presence of meat scraps or fatty food waste	remove meat and fatty foods from pile; cover with a layer of soil, leaves, or sawdust; use an animal-proof compost bin; turn pile to increase temperature
pile is damp and warm only in the middle	pile too small	make pile bigger

water contained in the soil is available to plants. The forces of attraction between water molecules are known as cohesion, and the forces of attraction between soil particles and water molecules are known as adhesion. Soil water is said to be adsorbed onto the soil particle surfaces. The water closest to a soil particle is held very tightly by the forces of adhesion, preventing the water from being available to plants. Adhesion is greatest at the soil-water interface and decreases with distance from soil particles. Both cohesion and adhesion give rise to capillary forces that hold soil water against the force of gravity and are largely responsible for upward and lateral movements of soil water.

The roots of crop plants must pull water away from soil particles and other water molecules—they must compete with the forces of adhesion and cohesion—to supply water to the plant. The total pore volume (porosity) of a soil and the size of soil pores play important roles in the availability of water to plants because they determine how much water the soil will hold (the water-holding capacity) and how tightly the water is held. The forces of cohesion and adhesion are much stronger in fine-textured soil, such as clay, because the small, negatively charged particles have a large amount of surface area that strongly attracts the positive charges on the hydrogen ions (H^+) in water, and because the water in the small pores is held very closely to particle surfaces, where adhesive forces are strongest. Conversely, coarse-textured (sandy) soil has larger mineral particles, less clay, and larger pores with less total pore volume, and therefore has lesser forces of cohesion and adhesion. Its ability to hold water (water-holding capacity) is much less than that of clay.

Plants are able to pull water from soil primarily because a continuous stream of water molecules flows from the root tip to leaf via the transpiration process, as discussed at the beginning of chapter 2, "Introduction to Horticulture." For every water molecule that evaporates from the leaf, one is pulled into the root from the soil by capillary forces in the plant's vascular system. Because plant roots must exert force to extract soil water, scientists measure soil water not only in terms of total quantity (soil moisture content) but also in terms of forces expressed in units of pressure or tension, such as atmospheres, bars, or pascals. These units quantify how tightly a soil holds water.

Water Availability

In a moist soil, soil particles are surrounded by films of water. As soil is wetted further, the water films surrounding each soil particle thicken. The water closest to the soil particles is held very tightly by forces of adhesion and is not available to plants. Water farthest from each soil particle is held loosely and can be absorbed by plants. The most loosely held water far from particle surfaces can be pulled downward by the force of gravity and moved beyond the root zone; this is called gravitational water. The water that remains in the root zone does so because the forces of cohesion and adhesion are stronger than the downward pull of gravity.

When all of the pores are filled with water, the soil is saturated, and the soil moisture tension (SMT), or the strength of soil water adhesion, is 0 kilopascals (kPa). Field capacity (FC) is the maximum amount of water that a soil can hold against the downward force of gravity after a soil has been saturated; soil water at FC is held at a tension of 30 kPa. The permanent wilting percentage (PWP) is the amount of water remaining in the soil when the water in the soil is held too tightly for plants to absorb it and plants wilt permanently. At PWP, soil water is held at 1,500 kPa in medium- and fine-textured soil and 1,000 kPa in sandy soil. Plant-available water is the soil water held between FC (30 kPa) and PWP (1,000–1,500 kPa). In practice, more than 90% of plant-available water is extracted from a soil

when the SMT reaches 100 kPa. The majority of soil water is held at an SMT of 30 to 100 kPa in medium- and fine-textured soils.

The FC level can also be measured in terms of the moisture content of the soil. Soil texture, structure, and organic matter content influence the amount of water held at FC and the amount of plant-available water. Sandy soil holds less water at FC than clay soil, for example. Soil texture is the property most responsible for water availability at FC. Table 3.5 presents soil water-holding characteristics for typical soil texture classes at FC, and table 3.6 provides data on average percentage of plant-available water for five soil textural classes.

Table 3.6 shows that FC increases as clay content increases. At FC (an SMT of 30 kPa), clay holds the greatest amount of water, followed by clay loam, silt loam, loam, and fine sand. At FC, sand can vary from 5 to 10% water, but clay loam can vary from 25 to 35% water (g H_2O/100 g soil). But along with the increased moisture content at FC, a greater amount of water is held at the PWP. At the PWP, clay soil holds more water unavailable to plants than does the clay loam (14.7 versus 10.2 g H_2O/100 g soil). Tables 3.5 and 3.6 illustrate that a clay loam soil actually has more plant-available water than a clay soil. In other words, fine-textured soil has the maximum total water-holding

Table 3.5.

SOIL WATER-HOLDING CHARACTERISTICS FOR TYPICAL SOIL TEXTURE CLASSES AT FIELD CAPACITY

Soil texture	Inches of water per ft of soil		Gallons of water per cu ft of soil
	Plant-available	Plant-unavailable	
sand, fine sand	0.4–1.0	0.2–0.8	0.33–0.66
sandy loam	0.9–1.5	0.9–1.5	0.66–1.00
loam	1.3–2.0	1.4–2.0	1.00–1.25
silt loam	2.0–2.1	2.0–2.4	1.25–1.33
clay loam	1.8–2.1	2.4–2.7	1.25–1.50
clay	1.8–1.9	2.7–3.0	1.33–1.66

Note: Values are approximate; 1 gal of water will cover 1 sq ft of soil 1.6 in deep, or 0.623 gal of water will cover 1 sq ft of soil 1 in deep.

Table 3.6.

SOIL MOISTURE CHARACTERISTICS OF FIVE SOIL TEXTURES; VALUES ARE PERCENT WATER EXPRESSED AS GRAMS OF WATER PER 100 G OF SOIL (10 G = 0.35 OZ)

Soil texture	Permanent wilting percentage (PWP)	Field capacity (FC)	Plant-available water (FC minus PWP)
fine sand	1.7	6.8	5.1
loam	6.8	18.1	11.3
silt loam	7.9	19.8	11.9
clay loam	10.2	26.5	16.3
clay	14.7	28.6	13.9

capacity, but medium-textured soil contains the most plant-available water.

The amount of water held at FC can be changed slightly by the addition of organic amendments and improved soil management practices. Adding organic matter to sandy soil increases the amount of plant-available water by encouraging aggregation and reducing the volume of some of the large pores so they can hold water against the downward force of gravity. Adding organic matter to fine-textured soil also encourages aggregation and increases the plant-available water by increasing the number of pores that are large enough to permit water extraction by plant roots but still small enough to hold the water against the force of gravity.

For gardening purposes, enough water should be available so that plant roots can absorb it quickly enough to maintain optimal growth and health. Most plants grow best at SMT of 30 to 50 kPa. If the soil is at FC or wetter for long periods, insufficient oxygen is available in soil pores for efficient respiration and other vital plant functions. As SMT exceeds 50 kPa, however, it becomes more difficult for plant roots to extract enough water to support maximum growth. It is generally acceptable for SMT to be significantly less than 30 kPa for a day or two after irrigation or rainfall and for SMT to reach or slightly exceed 50 kPa just before irrigation or rainfall.

A device known as a tensiometer is sometimes used in commercial horticulture operations to measure SMT so that irrigation needs can be accurately monitored. However, a tensiometer is not necessary to measure SMT in the garden. Dig a hole at the location and depth to be tested. If the soil sample does not form a ball when it is compressed, the soil is too dry, and SMT is most likely greater than 100 kPa. If the soil sample forms a ball that crumbles easily when thumb pressure is applied, the SMT is probably adequate if the soil is from an appropriate depth in the root zone. If the ball glistens and will not disintegrate and crumble under thumb pressure, the soil is too wet and the SMT is probably less than FC, which means that very few pore spaces are filled with air. The soil may be waterlogged and plant roots starved for oxygen. This technique for interpreting soil moisture is discussed in detail in chapter 4, "Water Management."

Water Balance

Scientists use specific terms to describe water inputs to, movement through, and losses from soil. Water inputs include natural rainfall (precipitation) and irrigation. Water losses include transpiration, evaporation, runoff, and leaching. Irrigation is the artificial application of water to soil, usually applied when rainfall is insufficient for crop growth. Not all rainfall or irrigation water penetrates the soil. Some water is lost as vapor (gas). Transpiration is water vapor lost at leaf surfaces through stomates, and evaporation is water vapor lost at the soil surface; these two vapor losses combined are called evapotranspiration. The home gardener has little control over transpiration but can reduce evaporation losses by applying mulch (straw, peat, gravel, wood chips, or opaque plastic sheeting) to the soil surface to act as a physical barrier to evaporation. When water evaporates, the salts that were dissolved in it remain in the soil. The hot, dry climate in many areas of California favors water evaporation and subsequent salt accumulation in the root zone. Overwatering or excess rainfall can result in liquid water loss (rather than vapor) because of runoff and leaching. Runoff, which is water lost as it flows over the soil surface, can lead to soil erosion because the water carries small soil particles with it. Leaching is the loss of water, dissolved plant nutrients, and salts that move downward in the soil profile beyond the root zone. When water moves into the soil, it is infiltration, whereas movement of water through the soil is called percolation, which is often accompanied by leaching.

Soil Fertility and Plant Nutrition

A fertile soil contains nutrient elements in amounts favorable for optimal growth of crop plants and in a plant-available form that crop roots can absorb (usually an inorganic chemical form). Plant nutrition is a plant's need for and use of 17 chemical elements for growth and development. Fertilization is the application of plant nutrient elements to the environment around a plant to meet its nutritional needs. Fertilizers and fertilization are discussed later in this chapter.

Essential Plant Nutrients

Today, 17 nutrient elements are known to be essential for plant growth and development (table 3.7). Of the 17 essential nutrients, 3 are taken from the air and water and the other 14 are absorbed from the soil by plant roots. All 17 elements are equally essential for plant growth and development, but the 14 derived from the soil are divided into three categories based on the relative amounts required: primary nutrients, secondary nutrients, and micronutrients (see table 3.7). The primary and secondary nutrients (also referred to as macronutrients) are measured as a percentage (parts per 100) of dry-weight tissue. Most of the micronutrients are measured on a parts per million (ppm) dry-weight basis. For example, a typical dried leaf from a healthy tomato plant might contain 3% nitrogen, 1% potassium, 100 ppm iron, and 100 ppm boron. The number of essential plant nutrients may increase in the future as scientists discover new information about the mineral nutrition of plants. For example, the micronutrient nickel is required in such small concentrations (50 to 100 parts per billion [ppb]) that it was not identified as an essential plant nutrient until 1987. The chemical forms of the nutrients commonly absorbed by plants given in table 3.7 will probably be updated in the future. Plants generally use simple ionic, inorganic nutrient molecules and cannot absorb complex organic (carbon-containing) or inorganic forms.

Essential nutrients are passively absorbed with soil water when plant roots absorb water containing dissolved nutrients. Water is absorbed by plant roots through transpiration (described above) and by diffusion, which occurs when the solute concentration inside the roots and surrounding cortical tissue is higher than the salt concentration in the soil solution. Active absorption of nutrients occurs when roots expend energy to extract nutrients from the soil solution.

Hunger Signs in Plants

Since ancient times, the appearance of plants has been used to help identify their health status. Plants speak through distress signals. The message may be that there is too little or too much water or that the plant is being infected with a disease caused by a microorganism such as a fungus, virus, or bacterium. Plants may show symptoms of attack by nematodes, insects, or rodents, or injuries from frost or lightning. The distress signals may also be linked to the nutritional status of a plant. Recognizing the general signs and symptoms of nutrient deficiency, toxicity, or imbalance can alert horticulturists and master gardeners to take appropriate steps to correct the problem.

Table 3.8 provides a brief overview of basic information on 14 essential nutrient elements supplied by soil (carbon, hydrogen, and oxygen are supplied by water and air). Soil fertilization techniques discussed later in this chapter allow gardeners some control over the supply of soil nutrients to plants.

Although plants require much higher concentrations of primary and secondary nutrients (parts per 100, or percentage) than micronutrients (parts per million or billion), all 17 essential elements must be present for the plant to be healthy. An excess, deficiency, or even an imbalance of these elements leads to individual symp-

Table 3.7.

ESSENTIAL PLANT NUTRIENTS

Element	Chemical symbol	Chemical forms absorbed by crop plants	Source
carbon	C	CO_2	air
hydrogen	H	H_2O	water
oxygen	O	O_2, H_2O	air, water
Primary nutrients			
nitrogen	N	NO_3^-, NH_4^+	soil solids*
phosphorus	P	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}	soil solids
potassium	K	K^+	soil solids
Secondary nutrients			
calcium	Ca	Ca^{2+}	soil solids
magnesium	Mg	Mg^{2+}	soil solids
sulfur	S	SO_4^{2-}	soil solids
Micronutrients†			
boron	B	BO_3^{3-}	soil solids
chlorine	Cl	Cl^-	soil solids
copper	Cu	Cu^+, Cu^{2+}	soil solids
iron	Fe	Fe^{3+}	soil solids
manganese	Mn	Mn^{2+}	soil solids
molybdenum	Mo	MoO_4^{2-}	soil solids
nickel	Ni	Ni^{2+}	soil solids
zinc	Zn	Zn^{2+}	soil solids

Notes:

*Some microorganisms that live in association with legume plant roots (*Rhizobia*, for example) can fix atmospheric nitrogen (N2), converting it to inorganic forms including ammonium ions ($NH4^+$), which crop plants can absorb. In this case, it can be said that some plants obtain their essential nitrogen from the air in symbiotic relationship with soil microorganisms.

†The term *micronutrient* has been restricted to mean elements known to be essential for the growth of higher plants that are needed in minute or trace quantities (ppm or ppb). Although the term *trace elements* is often used interchangeably with micronutrients, it has been used rather loosely in the scientific literature to describe elements with no known physiological function that may be toxic to plants and animals. Unfortunately, the terms *micronutrients, trace elements, microelements, heavy metals, trace metals,* and *trace inorganics* are used interchangeably. To avoid confusion, it is best to use the term *micronutrients* to refer to mineral elements that are essential for plant growth in trace quantities.

toms that can be generalized in most plants (see table 3.8). The most common nutritional problems in California are related to deficiencies of nitrogen, phosphorus, potassium, zinc, and iron, as well as toxicity symptoms caused by excesses in boron, chloride, and sodium. Because most nutritional disorders of plants are difficult to diagnose from visual symptoms alone, tissue and soil analysis are often needed as well. In some instances, plants may not show symptoms of nutritional deficiencies until severe stress has occurred.

Excellent publications (with photographs) that aid in identifying the hunger signs of plants can be obtained at nurseries and libraries, from your local University of California Cooperative Extension office, and on the Web at, for example, the UC Division of Agriculture and Natural Resources website, anrcatalog.ucdavis.edu/. If a nutrient problem must be diagnosed, a commercial laboratory can perform a diagnostic test using the specimen tissue for approximately $50 per sample. If a cheaper diagnosis is desired, sweet corn can be planted as a bio-

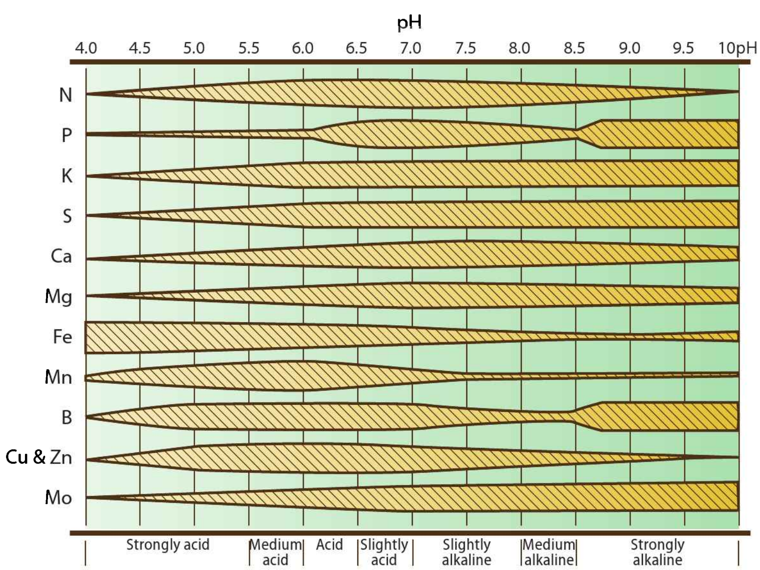
indicator. Corn expresses deficiency symptoms very clearly and unambiguously if an essential nutrient is lacking.

Nutrient deficiencies and toxicities can sometimes be corrected by the addition of appropriate inorganic fertilizers, manures, and amendments, and by soil and water management. For example, yellowing of leaves (chlorosis) can be a symptom of both overwatering and underwatering, as well as a symptom of nitrogen or sulfur deficiency. Iron chlorosis is associated with waterlogged conditions, and until the irrigation is corrected, iron chlorosis will persist no matter how much iron fertilizer is applied to the soil. Appropriate water management is very important, especially if water is of poor quality (high in soluble salts, chloride, sodium, or boron). When a plant transpires water through its leaves, any salts that were dissolved in the water are left behind. These soluble salts can accumulate and cause toxicities if rainfall is inadequate or if the amount of irrigation water applied is insufficient to leach these salts below the root zone. In plants grown on well-managed soil, the deficiency and toxicity symptoms described in table 3.8 may never appear.

What appears to be a deficiency symptom may sometimes be a normal occurrence for a plant. For example, subtropical plants such as lemon and avocado often have yellowish leaves in the cooler parts of the year then naturally turn green when the weather gets warmer. It pays to know your plants before taking corrective action that may not be necessary.

Figure 3.10

The effect of pH on the relative availability of selected plant-essential nutrients, as indicated by the width of the bar.



Effect of Soil pH

Most crops grow best when the pH is slightly acidic to neutral (pH 5.5–7.5) because mineral nutrients essential for plant growth derived from the soil are in chemical forms that plant roots can absorb in this pH range. At lower or higher pH, some nutrients become insoluble in water; they do not dissolve in the soil solution and cannot be absorbed by plant roots. Even if the plant nutrients are present, they may be unavailable to crop plants at extreme pH (less than 5 and greater than 9). Many plants exhibit deficiency symptoms unless soil pH is maintained between 6 and 7.5, but some plants prefer a more acid soil (e.g., azaleas, rhododendrons, and blueberries).

Soil pH is critical to plant growth not only because it affects the availability of essential nutrients (fig. 3.10) but also because it affects the solubility of detrimental or toxic mineral elements. For example, moderately to very acid soil (pH too low) may contain inadequate levels of plant-available nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, and molybdenum, but it may also contain toxic levels of aluminum and manganese. Very alkaline soil (pH too high) is often deficient in plant-available nitrogen, phosphorus, iron, or manganese, but it may also contain excessive concentrations of soluble salts or sodium, both of which are detrimental or toxic to plant growth.

The topsoil can lose calcium, magnesium, and potassium via leaching or

Table 3.8.

CHARACTERISTICS OF ESSENTIAL PLANT NUTRIENTS SUPPLIED BY SOIL SOLIDS

Nutrient	Function and comments	Absorption and movement in soil	Symptoms of deficiency	Symptoms of excess
nitrogen (N)	A constituent of amino acids, proteins, enzymes, and chlorophyll; important in photosynthesis, metabolism, protoplasm reactions; a component of nucleic acids, the backbone of DNA; important for many growth and developmental processes.	Taken up by plants primarily as NO_3^- (nitrate), since it is mobile and moves with soil water to plant roots, where absorption occurs. Plant roots can also absorb NH_4^+ (ammonium), but it is often bound to soil particle surfaces and cannot move as easily to the roots. Nitrogen in fertilizers is converted to NO_3^- by soil microorganisms. The nitrogen cycle and reactions in soil involving nitrogen are complex. Nitrogen leaches easily from the root zone. Deficiency symptoms begin in older tissue because nitrogen is mobile within plants and moves from older to younger tissue when in short supply. Several species of soil microbes fix atmospheric nitrogen (N_2), making it available to plants having a symbiotic relationship with them.	Slow growth, stunting, and yellow-green color (chlorosis); more pronounced in older tissue; "firing" of tips and margins (turning brown and dying); premature death.	Excessive vegetative growth, dark green color, excessive transpiration, reduced yield; delayed maturity; few fruit.
potassium (K)	Affects membrane permeability and H^+ relationships, stomatal opening/closing, internal water relations, cell division, starch and protein synthesis, and sugar translocation; increases size and quality of fruits and vegetables; increases disease resistance.	Taken up by plants as K^+. Unlike nitrogen and phosphorus, it is not synthesized into compounds in plants but instead stays as a simple ion in plant cells and tissues. Potassium is abundant in soils, but much of it is tied up in soil minerals and unavailable to plants.	Slow growth; leaf tip and marginal burn and necrosis (starts on more mature leaves); weak stalks (plants lodge); small fruit and shriveled seed.	Light green foliage; tendency for Ca^{2+} and Mg^{2+} deficiency symptoms to appear.
phosphorus (P)	Constituent of proteins, phospholipids, enzyme systems, and nucleic acids. Important for energy systems (ATP); stimulates early growth and root formation; promotes seed formation; important in photosynthesis.	Depending on soil pH, phosphorus is absorbed by plants as $H_2OPO_4^-$, PO_4^{2-}, or PO_4^{3-}. Soil phosphorus is often tied up chemically in relatively insoluble compounds. Phosphorus fertilizer uptake is more efficient in the presence of nitrogen. Synergistic effect is seen in banded fertilizer applications.	Slow growth, stunting, and purplish color (anthocyanins) on foliage or dark green color; dying leaf tips; marginal interveinal chlorosis; delayed maturity; poor fruit or seed development.	Excess can interfere with micronutrient absorption; may mimic Zn deficiency.
calcium (Ca)	Regulates membrane permeability and cell integrity, cell acidity; promotes cell elongation; essential component of plant cell walls and membranes; believed to counteract the toxic effects of oxalic acid.	Absorbed by plants as Ca^{2+}. It has limited mobility in plants, so young tissues show deficiency symptoms first. Often applied as a foliar spray on celery, apples, pears, and cherries. Excess calcium leads to high pH.	Reduced terminal growth of shoots (buds) and roots, resulting in plant death; blossom end rot of tomatoes, peppers, and melons; pits on apples and pears; tip burn of young leaves in lettuce and cabbage.	Excess Ca^{2+} interferes with micronutrient availability.
magnesium (Mg)	Constituent of chlorophyll molecule; required cofactor in many enzymatic reactions; aids mobility and efficiency of phosphorus.	Absorbed by plants as Mg^{2+}. It is essential for photosynthesis because it is a constituent of the chlorophyll molecule. Most commonly used in fertilization of celery and citrus. Very mobile within plants and can easily translocate from older to younger tissue under deficiency conditions.	Marginal necrosis and interveinal chlorosis, beginning in older leaves; leaves curl upward along margins; marginal yellowing with green "Christmas tree" area along midribs of leaves.	Excess Mg^{2+} interferes with uptake of Ca^{2+}.
sulfur (S)	Constituent of amino acids, proteins, and vitamins B_1 and H; activates enzyme systems; found in aromatic oils that impart characteristic smell and taste of onion, garlic, mustard, and cabbage relatives.	Taken up as SO_4^{2-}. Mobile and moves with soil water; deficiencies most common in sandy soil. Supplied as a component of fertilizers containing superphosphate, ammonium phosphate, magnesium phosphate, gypsum, and others. Also supplied by organic matter; soil bacteria convert organic forms to available form. Can be taken in through stomata as SO_2 where industrial air pollution is present, but prolonged exposure to high SO_2 levels causes severe damage to plants.	Similar to N and Zn deficiencies: stunted growth, yellow-green or light green leaves; sometimes affecting older leaves first. Spotting of leaves possible in some plants. Sulfur-deficient plants have lower protein content. Deficiency is most common in highly leached soils in humid climates.	Not known.

Table 3.8. cont.

Nutrient	Function and comments	Absorption and movement in soil	Symptoms of deficiency	Symptoms of excess
iron (Fe)	Essential for chlorophyll synthesis, stability; catalyst in respiration, photosynthesis, nitrogen fixation; important in cell division.	Taken up by plants as Fe^{3+}. Iron deficiency is common in western soils and can be due to high pH, poor aeration, high Mn concentrations, and lime. Turf, certain trees, and ornamentals are especially susceptible to iron deficiency.	Interveinal chlorosis of young leaves (veins remain green); twig dieback; reduced growth, and death in severe cases.	Mimics P, Mn deficiency.
manganese (Mn)	Important enzyme catalyst in many metabolic reactions; catalyst with Fe in chlorophyll synthesis; role in chloroplast structure; promotes pigment and vitamin C synthesis.	Taken up by plants as Mn^{2+}. Excess Mn induces Fe deficiency. Commercial citrus usually requires foliar sprays of Mn with Zn. Other tree crops may show deficiencies.	Interveinal marginal chlorosis of young leaves, but no sharp distinction between veins and interveinal areas as with Fe.	Mimics Fe deficiency; loss of foliage color, bronzing of leaf margins, necrotic areas.
zinc (Zn)	Important component of enzymes, including ones involved in synthesis of plant hormones (auxins) that regulate growth and development; role in chlorophyll synthesis.	Taken up by plants as Zn^{2+}. It is the micronutrient most often deficient in the West. Citrus, other tree fruits, nuts, grapes, beans, onions, tomatoes, corn, rice, and cotton generally require Zn fertilization. Terminal growth areas are affected first.	Interveinal chlorosis on young leaves; decrease in stem length; rosetting of terminal leaves; reduced fruit bud formation; twig dieback after first year.	Not known.
boron (B)	Role in differentiation of meristem cells; regulates carbohydrate (sugar) metabolism; formation of pectins, tissue lignification; facilitates Ca movement.	Taken up by plants as BO_3^{3-}. Intensive cropping has caused deficiencies to become more common. Like calcium, boron is not remobilized in plants once it is assimilated. Plants require a continuous supply at growing points. Deficiency symptoms are noted first in youngest tissues of plant.	Death, distortion, and stunting of terminal growth (meristems); witches'-broom; thickened, curled, wilted, chlorotic leaves; soft, necrotic spots on fruit, tubers; reduced flowering; cell differentiation errors.	Rare except in inland deserts with high boron-contaminated water; marginal necrosis on grape leaves.
copper (Cu)	Cofactor in enzymatic reactions important in carbohydrate and protein metabolism; role in chlorophyll and vitamin A synthesis.	Taken up by plants as Cu^{+} or Cu^{2+}. Fertilization is rarely needed in California. An exception may be tree crops and some plants growing on sandy or organic soils. Do not fertilize unless need has been established because copper can be highly toxic.	Stunted growth; dieback of terminal shoots in trees; poor pigmentation (carotenes), wilting, death of leaf tips; gum pockets, scabby rind on citrus.	Reduced growth; necrosis.
chlorine (Cl)	Required for photosynthesis; influences cell membrane permeability; prevents desiccation.	Taken up by plants as Cl^{-}. Moves readily in soil by mass flow.	Very rare; wilting, followed by chlorosis; branching of lateral roots; leaf bronzing.	Poor growth; marginal leaf necrosis.
molybdenum (Mo)	Required for nitrogen use; needed for conversion of NO_3^- into amino acids and for N_2 fixation; role in plant hormones.	Taken up by plants as MoO_4^{2-}. Deficiency symptoms are similar to nitrogen deficiency since molybdenum has a key role in nitrogen use by plants.	Stunting, reduced yield; lack of vigor, chlorosis; marginal scorching, cupping, rolling of leaves (whiptail of cauliflower).	Not known.
nickel (Ni)	Important enzyme component; important in nitrogen metabolism, especially during seed germination.	Not known.	Leaf tip necrosis.	Induces Fe and Zn deficiency; chlorosis symptoms.

removal by growing crops. With the loss of these particular cations, the soil can become more acidic.

Fertilization of Garden Soil

Garden soil is rarely fertile enough to supply all of the nutrients required for the best growth of plants. It is equally rare, however, for a soil to be deficient in several of the mineral nutrients that plants need. Because California soils contain most of the elements known to be essential to plants, it is necessary to add only the ones that are deficient in a particular soil. Too little fertilization results in poor plant growth and appearance. Too much fertilization, regardless of the source, is unnecessarily expensive, may cause plant injury, and may pollute groundwater or surface water.

Types of Fertilizer

Inorganic fertilizer

Commercially available inorganic fertilizers vary in their plant nutrient content. Table 3.9 provides an analysis of the primary nutrient content of common inorganic fertilizers. Complete inorganic fertilizers are mixes containing the three primary nutrients: nitrogen, phosphorus, and potassium. Incomplete fertilizers may contain a single nutrient material, such as ammonium nitrate (contains nitrogen only), or double nutrient compounds, such as ammonium phosphate (contains nitrogen and phosphorus). The term *complete* should not be interpreted to mean that the fertilizer supplies all the nutrients a plant needs, nor should it be interpreted to mean that the primary nutrients are the only ones supplied in the fertilizer. In fact, the fertilizer may have constituents other than those listed on the label, but if their proportions cannot be guaranteed consistently, they are not listed.

By law, the guaranteed content of the fertilizer, expressed as a percentage of each plant nutrient supplied, must be stated on the bag. Under this labeling method, the first number shown is the percentage of nitrogen (N); the second is the percentage of phosphorus (P), expressed as P_2O_5 (phosphate); and the third is the percentage of potassium (K), expressed as K_2O (potash) (fig. 3.11). A 100-pound bag of a 12-12-12 fertilizer contains 12 pounds each of nitrogen, phosphate, and potassium. The other 64 pounds in the bag is filler, which facilitates even spreading of fertilizer. (See the notes in table 3.9 about fertilizer grades and correcting for the elemental content of phosphorus and potassium.) If a secondary nutrient or micronutrient has been added to the fertilizer, it may be listed on the bag with its guaranteed percentage. Sample calculations for applying fertilizer are given in the sidebar on page 68.

Inorganic fertilizers are characteristically fast acting and relatively low in cost. Some inorganic fertilizers, such as ammonium fertilizers, can acidify the soil (lower the pH) with long-term use, while others, such as calcium nitrate, tend to raise pH. Because inorganic fertilizers are salts, they dissolve and release nutrients readily. Key disadvantages are their potential to contaminate the environment through runoff or leaching and to “burn” crops if overapplied or mismanaged. Slow-release nitrogen fertilizers are available at much higher cost; their release rates are governed by environmental factors such as soil moisture content and temperature. Slow-release inorganic nitrogen is sometimes called water-insoluble nitrogen (WIN). Using these products reduces the chances of environmental contamination and crop injury because relatively small amounts of nitrogen are present in a soluble form at any time. When used properly, plants receive a consistent supply of nitrogen, and fewer applications can be made than when using conventional fertilizer.

In addition to macronutrient fertilizers, micronutrients may be applied (see tables 3.7 and 3.10). Often, the long-term solution to

Table 3.9.

ANALYSIS* OF COMMON INORGANIC AND SYNTHETIC FERTILIZERS

Fertilizer	Formula	Nitrogen (N %)	Available phosphorus (P_2O_5 %)†	Potassium (K2O %)‡
urea	$CO(NH_2)_2$	45	0	0
ammonium nitrate	NH_4NO_3	33.5	0	0
ammonium sulfate	$(NH_4)_2SO_4$	21	0	0
calcium nitrate	$5Ca(NO_3)_2 + NH_4NO_3 \cdot 10H_2O$	16	0	0
sodium nitrate	$NaNO_3$	16	0	0
ammonium phosphate (monoammonium phosphate)	$NH_4H_2PO_4$ (mostly)	11–16	20	0
diammonium phosphate	$(NH_4)_2HPO_4$	18	46	0
superphosphate	$Ca_2H_2(PO_4)_2$	0	20	0
basic slag§	Ca, Mg, Al silicates	0	8	0
rock phosphate	$3Ca_3(PO_4)_2 \cdot CaF_2$	0	5 (available)	0
muriate of potash	KCl	0	0	60
potassium sulfate	K_2SO_4	0	0	50
potassium nitrate	KNO_3	13	0	44
12-12-12	—	12	12	12
8-16-6	—	8	16	16
5-10-5	—	5	10	5
slow-release fertilizers#	varies	10–41	0–14	0–14

Source: Adapted from California Fertilizer Association 1998.

Notes:

*Sometimes the terms *analysis* and *grade* are used interchangeably. The term *grade* should be applied only to the three primary nutrients, N, P, and K. The fertilizer grade is expressed as the guaranteed percentage of nitrogen, phosphoric acid, and potash. For example, a 12-12-12 grade would contain 12% nitrogen, 12% available phosphate, and 12% potash. The ratio is the relative proportion of each of the primary nutrients. A 12-12-12 grade is a 1:1:1 ratio. A zero in a grade or ratio means that the particular nutrient is not present in that fertilizer.

†Phosphoric acid (P_2O_5) actually contains 43% phosphorus. The percentages given for the oxide can be converted to percentages of the element by multiplication: $P = P_2O_5 \times 0.43$.

‡Potash (K_2O) actually contains 83% potassium. The percentages given for the oxide can be converted to percentages of the element by multiplication: $K = K_2O \times 0.83$.

§Basic slag is a by-product of the steel manufacturing process; it contains lime, phosphates, and small amounts of other plant nutrients, such as sulfur, manganese, and iron. Basic slags may contain from 10 to 17% phosphate (P_2O_5), 35 to 50% calcium oxide (CaO), and 2 to 10% magnesium oxide (MgO). The available phosphate content of most American slag ranges from 8 to 10%.

#Only nitrogen is typically slow release in these products. Percentages ranges of nutrients are typical.

such deficiencies as iron, zinc, and manganese is to correct the soil pH so that they become available. A major limitation to the efficacy of these micronutrients is that until the pH is corrected, applications may be required frequently. They can be applied directly to the plant foliage or to the soil. Metal salts, such as copper sulfate, can burn foliage if applied at too high a rate. Soil application should be directed to areas of active root growth. Chelates of these metal nutrients are often used for soil application. They are less affected by soil pH than nonchelated forms but are more expensive than inorganic salts.

Manure and organic fertilizer

Manures are composed primarily of animal excrement, plant remains, or mixtures of both. When used correctly, manures can be a good organic garden fertilizer. They supply garden plants with many essential nutrients and can help improve soil structure. Until they decompose, most plant nutrients in manures are in carbon-containing organic forms. The general belief that plant or animal manures are better sources of plant nutrients than inorganic forms is incorrect. For organic nutrient sources to be beneficial to plants,

Sample Calculations for Applying Fertilizer

Problem 1

You have decided that 20 flower and shrub beds 10 × 10 feet each are to be fertilized at the rate of 2 pounds of nitrogen (N) per 1,000 square feet with a 10-12-12 fertilizer that costs $15 for 100 pounds. How many pounds of fertilizer will be needed? How much will it cost?

Solution

Find the total area to be fertilized given the dimensions of the beds:

10 × 10 ft/bed × 20 beds = 2,000 sq ft

Find the amount of fertilizer required given the application rate, amount of N in the fertilizer (10 lb in 100 lb of 10-12-12), and area to be fertilized:

(2 lb N ÷ 1,000 sq ft) × (100 lb fertilizer ÷ 10 lb N) × 2,000 sq ft = 40 lb fertilizer

Find the cost of the fertilizer required given the amount needed and the cost:

40 lb fertilizer × ($15 ÷ 100 lb fertilizer) = $6.00

Problem 2

How much 20-10-5 fertilizer would it take to apply 2 pounds of phosphorus (P) per 1,000 square feet to a garden whose dimensions are 20 × 10 feet?

Solution

Find the area to be fertilized given the garden dimensions:

20 × 10 ft = 200 sq ft

Find the amount of fertilizer to apply given the application rate, amount of phosphorus in the fertilizer (the fertilizer grade expresses P as P_2O_5, which is 43% P), and the area to be fertilized:

(2 lb P ÷ 1,000 sq ft) × (100 lb fertilizer ÷ 10 lb P_2O_5) × (1 lb P_2O_5 ÷ 0.43 lb P) × 200 sq ft = 9.3 lb fertilizer

Note: It is acceptable to round this down to an application of 9 pounds. To convert 9.3 lb to pounds and ounces or pounds and cups of dry measure, see the conversion table at the end of this book.

Problem 3

How much ammonium sulfate would it take to apply 1 pound of nitrogen (N) per 1,000 square feet to a lawn that is 5,000 square feet?

Solution

Find the amount of fertilizer given the application rate, amount of nitrogen in the fertilizer (ammonium sulfate, 21-0-0, contains 21% N), and the area to be fertilized:

(1 lb N ÷ 1,000 sq ft) × (100 lb fertilizer ÷ 21 lb N) × 5,000 sq ft = 23.81 lb ammonium sulfate

Note: It is acceptable to round this up to an application of 24 pounds.

Problem 4

How much 20-4-10 liquid fertilizer must be applied to a 2,000-square-foot lawn to obtain a fertilization rate of 2 pounds nitrogen (N) per 1,000 square feet?

Solution

Calculating the amount of liquid fertilizer to use is more difficult than with dry fertilizer because the analysis is expressed on a percentage basis but the amount of fertilizer in the container is expressed on a volume basis. Assume that 1 gal of fertilizer weighs 11.5 lb. Find the amount of liquid fertilizer to apply given the application rate, weight of N per pound of fertilizer, volume of liquid fertilizer to apply, and the area to be fertilized:

(2 lb N ÷ 1,000 sq ft) × (1 lb fertilizer ÷ 0.20 lb N) × (1 gal fertilizer ÷ 11.5 lb fertilizer) × 2,000 sq ft = 1.74 gal fertilizer

Note: It is acceptable to round this up to an application of 1 gallon and 3 quarts.

the nutrients must be changed into chemical forms that plants can absorb and use (see table 3.7). Because manures may contain undesirable weed seeds and relatively high amounts of salts, they should be used cautiously where weeds or salts could create problems. Apply manure by mixing it into the soil at least 1 month before preparing the soil for planting. Advance application allows time for partial rotting or decomposition of the manure and leaching of excess mineral salts from the root zone before planting.

Manures can vary greatly in nutrient content. Table 3.11 provides an average analysis of the primary nutrient content of common organic fertilizers. It is difficult to guarantee the analysis because it varies from season to season and according to the length of time the fertilizers have been exposed to decomposition. Manures are typically more complete than most inorganic fertilizers because they contain most or all of the essential nutrients required for plant growth and development. Dry chicken manure is the most concentrated animal manure with respect to primary nutrients, whereas dairy manure is much less concentrated and supplies less-readily-available nitrogen to plants. Steer manure from animals fattened on concentrated feeds is richer in nutrients than is dairy manure.

The recommended rates of manure application for fertilizing vegetables are given in the section “Soil Improvement and Preparation” in chapter 13. If dairy or steer manure is used annually, decrease the amount applied each year: reduce the application rate to 70% the second year, 60% the third year, and 50% every year thereafter. As time goes on, a fraction of material applied from the previous year(s) slowly decomposes, making a contribution to this year’s contribution. Because two of the breakdown products of organic matter are ammonium ions (NH_4^+) and carbon dioxide (CO_2), or carbonic acid (H_2CO_3) when it is dissolved in water, repeated additions of various organic materials tend to lower the pH of soil over time.

Also, it is usually assumed that all organic fertilizers release nutrients slowly. Some organic sources, such as blood and fish meal, while releasing nutrients more slowly than inorganic salts like calcium nitrate, may release their nitrogen in as little as 6 to 8 weeks in the warm soil conditions found in much of California.

Only low concentrations of nutrients are found in compost teas (extracts made from soaking compost in water). These are extremely variable in their nutrient content, depending on compost composition and the temperature and length of extraction time. Compost teas may help control some plant diseases and are most valuable as a secondary source of nutrients in a regular nutrition program.

The principal limitations of organic fertilizers are their bulk, water content, availability, odor, potential salt and weed seed hazards, and expense per pound of nutrient. Organic concentrates, such as bonemeal, cottonseed, and fish emulsion, also contain a variety of nutrients, but their cost per pound of nutrients is higher than that of inorganic fertilizers. The value of manures and organic concentrates do not lie solely in their nutritional value, however. Organic materials also have beneficial effects on the soil's physical properties, decreasing soil bulk density, improving water infiltration and nutrient-holding capacities, and often adding small amounts of micronutrients.

Table 3.10.

NUTRIENT CONCENTRATION OF MICRONUTRIENT FERTILIZERS

Material	Nutrient concentration
Boron (B) materials	**Percent B**
borax	11
boric acid	17
solubor	21
Copper (Cu) materials	**Percent Cu**
copper chelates Cu EDTA Cu HEDTA	 13 9
copper sulfate	25
cupric oxide (very insoluble)	89
Iron (Fe) materials	**Percent Fe**
ferrous sulfate	20
feric sulfate	20
iron chelates Fe EDTA Fe EDDHA (works best in high-lime soils)	 9–12 6
iron lignosulfate	5–11
iron oxalate (very soluble)	30
Manganese (Mn) materials	**Percent Mn**
manganese chelate (EDTA)	62–70
manganese sulfate	24
Zinc (Zn) materials	**Percent Zn**
zinc chelate Zn EDTA Zn HEDTAs	 9–14 9
zinc lignosulfate	5–12
zinc phosphate	51
zinc sulfate	22–36

Source: Adapted from California Fertilizer Association 1998.

Selecting and applying fertilizers

When the gardener is faced with the plethora of nutrition products available at the garden center, the choice must be made whether to use inorganic fertilizer that supplies only nutrients or a bulky organic, such as compost or manure, that also contributes organic matter content. The quality of what is marketed as compost varies considerably and there are no guarantees, so the gardener should make sure the material has the smell and appearance of good compost. Organics typically cost more per unit of nutrient that inorganics but often contain other nutrients in trace amounts. If an inorganic is selected, there is the choice of whether to use a complete fertilizer or a single-source one. Fruit trees in California rarely need supplemental phosphorus, so it doesn't make sense to apply this nutrient when it's not needed. When looking at single-source fertilizers, there is also the question of their impact on soil pH. Ammonium fertilizers lower pH, and nitrate fertilizers tend to raise it. Certain inorganic fertilizers contain six or more nutrients; these are best used as container media fertilizers, since most soil does not require that many supplemental

Table 3.11.

ANALYSIS* OF ORGANIC FERTILIZERS

Fertilizer	Nitrogen† (N %)	Phosphorus‡ (P_2O_5 %)	Potassium§ (K_2O %)
Bulky organic materials			
chicken manure (dry)	2.00–4.50	4.60–6.00	1.20–2.40
steer manure (dry)	1.00–2.50	0.90–1.60	2.40–3.60
dairy manure (dry)	0.60–2.10	0.70–1.10	2.40–3.60
peanut hulls	1.50	0.12	0.78
sheep manure (fresh)	1.05	0.40	1.00
poultry manure (fresh)	1.00	0.85	0.45
horse manure (fresh)	0.65	0.25	0.50
grain straw	0.60	0.20	1.10
seaweed (kelp)	0.60	0.09	1.30
cattle manure (fresh)	0.55	0.15	0.45
sawdust and wood shavings	0.20	0.10	0.20
Organic concentrates			
blood meal (dried blood)	13.0	1.5	2.5
hoof and horn meal	12.0	2.0	0
fish meal	10.0	6.0	0
soybean meal	7.0	1.2	1.5
fish scrap	5.0	3.0	0
bonemeal	4.0	23.0	0
cocoa shell meal	2.5	1.5	2.5
wood ashes#	0	2.0	6.0

Notes:
*Analysis reported is an average for primary nutrients without accounting for losses caused by leaching or decomposition; 1 cu ft of air-dry manure weighs about 25 lb.
†Analysis based on dry weight except for fresh manures, which contain about 65 to 85% water.
‡Analysis based on dry weight except for fresh manures, which contain about 65 to 85% water. Phosphoric acid (P_2O_5) actually contains 43% phosphorus. The percentages given for the oxide can be converted to percentages of the element by multiplication: $P = P_2O_5 \times 0.43$.
§Analysis based on dry weight except for fresh manures, which contain about 65 to 85% water. Potash (K_2O) actually contains 83% potassium. The percentages given for the oxide can be converted to percentages of the element by multiplication: $K = K_2O \times 0.83$.
#Burning eliminates organic matter and forms inorganic compounds.

nutrients. Choosing dry or liquid formulations is based on convenience; liquid and water-soluble fertilizers are easy to mix and apply with a hose-end sprayer.

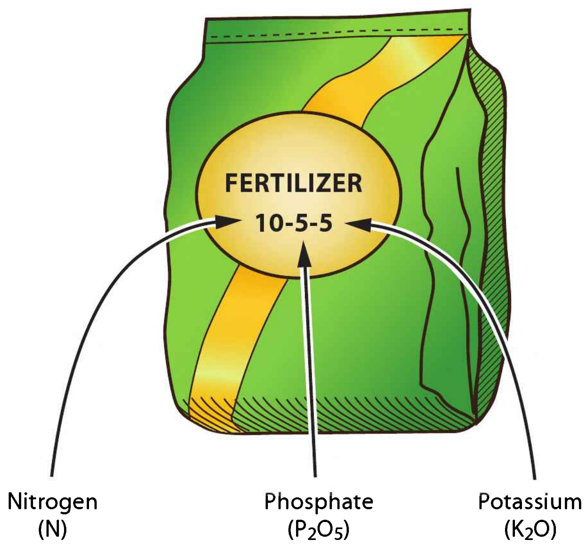
When applying either organic or inorganic fertilizers, use good judgment based on local experience to supply the necessary plant nutrients in the amounts needed. Many successful gardeners use a combination of inorganic and organic fertilizers. Regardless of which fertilizers you apply, use them efficiently to reduce cost, prevent plant injury, and to prevent unwanted contamination of the environment, for example from leaching of excess nitrogen. For more information, see “Fertilizer Application Methods, Rates, and Timing,” below.

Fertilizer or Amendment: Which Is It?

Whether a material is considered a soil amendment or a fertilizer is usually determined by its effect on plant growth. Fertilizers affect plant growth directly by improving the supply of available nutrients in the soil. Amendments, on the other hand, influence plant growth indirectly by improving the soil’s physical properties (e.g., tilth, water infiltration) or chemical properties (e.g., pH, salinity). The distinction between

Figure 3.11

Sample label of a fertilizer bag.



these two concepts is clear when you compare materials such as ammonium nitrate (a fertilizer) and gypsum (an amendment). It is more difficult to distinguish between amendments and fertilizers when evaluating natural or organic products. Animal manure, for example, falls into either category, depending on your reasons for applying it. Manure can be a source of nutrients, but it can also supply significant quantities of organic matter, which improves soil aeration and water retention.

California fertilizing materials law eliminates some of the confusion by defining specific quality standards and characteristics for the production and sale of these materials. Legal definitions of fertilizing materials can be found in *Fertilizing Materials Laws and Regulations* (see the California Department of Food and Agriculture website, cdfa.ca.gov). Important legal definitions include the following:

- **Packaged soil amendment**. Any substance distributed for the purpose of promoting plant growth or improving the quality of crops by conditioning soil solely through physical means. This category includes all of the following: hay; straw; peat moss; leaf mold; sand; wood products; any product or mixture of products intended for use as a potting medium, planting mix, or soilless growing media; manures sold without guarantees for plant nutrients; or any other substance or product that is intended for use solely because of its physical properties.
- **Natural organic fertilizer**. Materials derived from plant or animal products containing one or more nutrients other than carbon, hydrogen, and oxygen that are essential for plant growth; and which may be subjected to biological degradation processes under normal conditions of aging, rainfall, sun curing, air drying, composting, rotting, enzymatic or anaerobic/aerobic bacterial action, or any combination of these; and which shall not be mixed with synthetic materials or changed in any physical or chemical manner from their initial state except by physical manipulations such as drying, cooking, chopping, grinding, shredding, or pelleting.
- **Commercial fertilizer**. Any substance that contains 5% or more of nitrogen (N), available phosphoric acid (P_2O_5), or soluble potash (K_2O), singly or collectively, that is distributed in California for promoting or stimulating plant growth. Commercial fertilizer includes both agricultural and specialty fertilizers.
- **Specialty fertilizer**. Any packaged commercial fertilizer labeled for home gardens, lawns, shrubbery, flowers, and other similar noncommercial uses. These products may contain less than 5% nitrogen, available phosphoric acid, or soluble potash, singly or collectively, detectable by chemical methods.

Nutrients Most Commonly Needed from Fertilizers

Because nitrogen is naturally low in almost all soil in California, additional amounts are needed to ensure optimal plant growth. Nitrogen may be the only supplement necessary, however. The most prominent plant symptom of nitrogen deficiency is chlorosis (yellowing) of older leaves.

Phosphorus may be low in some highly weathered California soil that is often reddish and has hardpan or claypan layers in

the subsoil. Other soil may be low in available phosphorus because of long-term cropping or because of alkalinity, which makes soil phosphorus unavailable. Soil analysis can help to diagnose phosphorus deficiency; plant symptoms include stunting and purplish coloration of the older leaves. Phosphorus is relatively immobile in soil. With few exceptions, trees do not respond to supplemental fertilization in California.

Potassium is not commonly needed in most gardens because California soils naturally contain this element. If there is any question, soil analysis can help to diagnose a potassium deficiency. Deficiency symptoms include scorching (firing, or necrosis) along leaf margins of older leaves, slow growth, weak stems, and poorly developed root systems.

Iron deficiency is common in acid-loving plants grown in alkaline soil. Symptoms include interveinal chlorosis in younger leaves. Iron deficiency can be corrected by acidifying the soil or using iron fertilizers (iron chelate or iron sulfate) according to package directions.

Zinc deficiency may occur in gardens where the surface soil has been removed during building and leveling operations. Soil analysis may help to diagnose a deficiency. Plant symptoms may include interveinal chlorosis in younger leaves, the growth of small leaves, and leaves clustered in a circular pattern near branch tips (rosette formation). Fertilizers containing zinc, such as zinc sulfate or zinc chelate, can correct the problem.

Sulfur deficiencies are not widespread in California, but they may occur in areas with high rainfall (leaching) or with irrigation water containing little or no sulfur. Soil tests for sulfur deficiency may be difficult to interpret.

Soil Testing and Interpretation

In many cases, plant diagnosis will be adequate for identifying deficiencies. If there is a persistent problem that is causing problems or the garden is a new site, it might be worth having a laboratory analyze the soil. A complete analysis can be done for under $50 in most areas. The lab will provide an interpretation for how the soil will affect plant growth and what nutrients to supply.

Most commonly, in much of California, an analysis for pH, salinity, boron, sodium, and chloride will be more important for identifying excesses than deficiencies. Many garden soils get too many nutrients (too much fertilizer), and water is often not properly managed. Pushing plant growth with a lot of fertilizer and water inputs often causes too much growth, and consequently more mowing and pruning. Remember that landscape plants just need to look good, and fruit yield is not important. Review the management practices that have been used in the garden before assuming that there is a problem with the soil.

Fertilizer Application Methods, Rates, and Timing

Fertilizer application methods, rates, and timing should be matched to the nutritional needs of particular plants and to the nutrient deficiencies of the soil. The most effective strategy varies according to the specifics of the gardening situation. Fertilizers may be applied to the soil surface, below the soil surface (subsurface application), to the plant foliage (foliar application), through the irrigation system (fertigation, or chemigation), or mixed with certain pesticides. More than one method of application may be needed during the growing season because plants may require applications at different stages of growth and development. According to the *Western Fertilizer Handbook* (California Plant Health Association 2002), the following points should be considered when choosing the appropriate method of fertilizer application:

- rooting characteristics of the species being planted

- plants' demand for various nutrients at different stages of growth
- physical and chemical characteristics of the soil
- physical and chemical characteristics of the fertilizer materials being applied
- moisture availability
- type of irrigation system, if irrigation is the sole or major water source

Broadcasting

The broadcast method of applying fertilizer, which is effective for large lawn areas or garden plots, consists of uniformly distributing dry or liquid fertilizer materials onto the soil surface. Many home gardeners use a drop spreader or spinning-type spreader to facilitate uniform application of dry fertilizer. Before preparing the seedbeds for planting vegetables, annuals, or turfgrass, fertilizer may be broadcast and promptly worked into the soil to prevent nitrogen losses through ammonia volatilization. Broadcasting is an effective means of applying nitrogen and potassium to existing large gardens and turf areas.

All fertilizers that can be broadcast on the soil surface can be injected in a subsurface application. Injection requires special equipment, but it can be an excellent method of putting immobile nutrients into the root zone to allow for more efficient uptake by plant roots or to conserve nutrients that are lost when they are applied to the soil surface.

Band placement

Band placement is a subsurface application method in which narrow bands of fertilizer are placed several inches to the side or below seeds or established plants. The plants, soil type, and fertilizer determine whether bands are placed to the side and below the seed or only directly below the seed. Fertilizer placed too close to seeds or transplants may damage roots or inhibit seed germination.

In vegetable gardens, band placement at seeding time is an alternative to broadcasting. Band applications of a phosphate-containing fertilizer at planting may be more effective than broadcasting because phosphorus has limited mobility in the soil. With a band application, the phosphorus will be closer to the plant roots for uptake. Ammonium phosphate (16-20-0 or 11-48-0) and several of the complete fertilizers, such as 5-10-5, 8-16-16, or 12-12-12, are acceptable materials. Dig a shallow trench 2 to 4 inches to one side of the row and 2 to 4 inches below where the seed is to be placed. Place 1 to 2 pounds of fertilizer per 100 feet of row in the bottom of the trench and cover it with soil. When using furrow irrigation, place the fertilizer band between the seed or plant row and the irrigation furrow. If sprinkler irrigation is used, band the fertilizer on either side of the row.

Sidedressing

A method appropriate at critical growth stages, sidedressing is the application of dry fertilizer beside actively growing plants to replace nutrients that have been leached or used up in the growth process. For example, after vegetable plants are well established and 3 to 4 inches tall, sidedressing with nitrogen is very effective at rates similar to those for banding fertilizer. The trench should be at least 4 inches from the side and below the plant row to prevent burning the roots. Subsequent irrigations will move the nitrogen into the root zone. Do not sidedress with large amounts of nitrogen after the vegetable plants have begun to mature because the fertilizer will encourage vegetative growth at the expense of fruiting and of storage organ production.

Foliar applications

Applying fertilizer to plant leaves can correct micronutrient deficiencies. Spray the foliage using equipment like that used for pesticide application (but do not use equipment that has contained pesticides). Because plant response can be affected by droplet size and other technicalities, this method is not recommended for general fertilizer application. Attempting to supply macronutrients such as nitrogen in suffi-

cient quantities with this method is very expensive and inefficient because only very small amounts of nutrient elements can enter a plant through leaf tissue. However, it is feasible to supply adequate amounts of certain formulations of micronutrients by this method. To fertilize vines and fruit and nut trees, certain nutrients can be applied to the foliage in combination with pesticide sprays during the latter part of the dormant season. Check labels for specific instructions regarding legal requirements and usage.

Organic materials

Most organic materials must be incorporated into the soil because of their bulk. If these are applied as mulches rather than incorporated, plants do not derive as much benefit from them, since much of the nitrogen can volatilize and be lost as a gas. Certain soluble organic materials, such as seaweed and fish emulsion, can be applied foliarly.

Fertilizing landscape plants

To fertilize newly planted trees, shrubs, vines, and ground covers, refer to the nitrogen fertilization recommendations (rate, frequency, and timing) in table 12.2.

Managing and Amending Soil Physical and Chemical Properties

Optimal plant growth depends on favorable physical as well as chemical properties. Soil with good physical structure and good tilth can hold and provide adequate quantities of nutrients, water, and air to plant roots. It will also drain well when large quantities of water are applied and will be easy to work without becoming sticky when wet and crusted when dry. Soil with acceptable levels of pH, plant-essential nutrients, and soluble salts can provide adequate nutrition and chemical properties for plant growth and development. No amount or type of soil amendment will overcome poor initial site design or improper horticultural management.

Sometimes the soil to be gardened or landscaped has been graded, layered, compacted, or otherwise modified to construct a suitable lot for a building foundation, a landscape berm, or another feature. Unfortunately, such soil alterations are performed to engineering or architectural standards, not horticultural standards. The discrepancy in the two standards often presents considerable problems in establishing and maintaining landscape and garden plant materials.

In mature landscapes, detrimental changes in soil chemical or physical properties can occur with use and management of the area. Soil compaction is one of the most common and potentially harmful changes that occurs as a result of foot and vehicle traffic. Overfertilization can create high levels of soluble salts, and the long-term use of acid-forming fertilizer can lower pH, possibly to an undesirable level.

Mulching

Mulching is the practice of applying materials, such as newspapers, old carpeting, rocks, or bark, to the soil surface. This practice protects the soil from compaction, reduces erosion, suppresses weeds, and reduces evaporation of water. When organic mulches are used, soilborne organisms (soil fauna) slowly churn it back into the soil and eventually move it through the soil profile. Organic mulches are best when they are coarse (1–3 in long) woody material. Leafy, grassy materials break down more rapidly and require more frequent application. In wet weather, grassy materials can become soggy and anaerobic and can cause problems around established plantings. Mulches should be kept 4 to 6 inches away from plant stems to avoid trunk diseases and should be spread 2 to 4 inches deep to obtain maximum benefits.

When to Amend Landscape and Garden Soil

Adding one or more soil amendments, regardless of existing soil conditions, is commonly considered essential to success-

ful establishment of new plantings or rejuvenation of poorly growing existing ones. However, most new plantings do not require soil amendments. It is usually impractical to effectively amend the physical properties of whole landscape or garden areas because of the expense and volume of soil required to effectively amend soil (tables 3.12, 3.13). While individual planting holes can be amended, the effect is temporary because roots of woody and other perennial plants eventually grow out of the planting hole into native soil. Research findings show that amending tree and shrub planting holes or entire landscape and garden areas is warranted only in extreme situations like those discussed earlier in this section. If a situation arises where amending individual planting holes is necessary, the holes should be constructed to be about four times the diameter but the same depth as transplants' root systems.

Physical soil amendments can enhance the tilth and manageability of small beds and garden areas where ornamental plants and vegetable crops are regularly removed and replanted. Occasional additions of organic matter (such as plant residues, compost, or manures) in these plantings ensure

Table 3.12.

ORGANIC AMENDMENTS FOR IMPROVING GARDEN SOIL TILTH

Organic amendment	Amount to add per 100 sq ft	Synthetic nitrogen to be added in weight of amendment per 100 lb*
leaves	75 lb (3–4 bu)	0.5–1.0 lb
straw	60 lb (1 bale)	0.5–1.0 lb
hay, legume	60 lb (1 bale)	none
hay, grass	60 lb (1 bale)	0.25–0.50 lb
corncobs (ground)	50 lb (2 bu)	1.0–1.5 lb
sawdust	50 lb (2 bu)	1.25–1.50 lb
bark or wood chips	50 lb (2 bu)	1.25–1.50 lb
compost	10–20 cu ft	none
peat moss	6–10 cu ft	none
lawn clippings	4 bu	none

Note: *1 lb nitrogen = 10 lb of 10-10-10 fertilizer or 3 lb of ammonium nitrate (33.5-0-0).

Table 3.13.

VOLUME OF ORGANIC SOIL AMENDMENTS TO ADD BASED ON TREATMENT DEPTH

% Amendment	Volume of soil amendment (cu yd/1,000 sq ft) at depth of amended soil		
	3 in	6 in	9 in
30	2.78	5.56	8.33
35	3.24	6.49	9.72
40	3.70	7.41	11.13
45	4.16	8.34	12.52
50	4.63	9.26	13.88

Source: Adapted from California Fertilizer Association 1998.

a continuous supply of energy for soil microorganisms. As the soil microbes decompose the organic matter, they convert it into inorganic nutrients that can be used by growing plants. They also help to maintain good soil structure through the release of compounds into the soil environment that cement small soil particles together.

An appropriate physical or chemical amendment may also be feasible in beds or containers where small woody or perennial plants with unique, demanding soil requirements will be located. In existing woody or perennial plantings in a landscape or garden, physical soil problems are normally impractical to remedy.

Before proceeding to amend a new or established landscape or large garden area, evaluate and analyze the site to determine whether an amendable problem exists. Soil across the site should be examined with probes, augers, or shovels to check for layered soil and compaction zones at or below the surface. Original grading specifications and techniques should also be reviewed and considered to identify subsurface changes that could cause soil structure problems. A soil test of pH and soluble salts can be helpful before planting an area, but it is sometimes more appropriate as a tool for diagnosing poor performance of established plants. The soil should be evaluated for extremes in soil texture, such as high clay or sand content. The rates of water infiltration and drainage (percolation) should be estimated (see sidebar).

The first rule for amending soil is that an amendable problem must be present. Amendment of the soil is usually warranted and should be considered if any of the following are discovered:

- soil texture analysis with an extremely high percentage of clay (> 30%), which greatly reduces aeration and tilth of a soil, or an extremely high percentage of sand (> 70%), which greatly reduces water- and nutrient-holding capacity
- infiltration or percolation less than a rate of ¼ inch per hour
- layers of soil with different textures
- compaction in the soil surface or in a layer below the surface
- pH beyond the acceptable range of the plants being grown (5.0–8.0 for most plants)
- high level of soluble salts (an EC test value of 2.0 dS/m or greater for sensitive plants, 4.0 dS/m or greater for other plants)

The second rule for amending soil is that the amendment must be uniformly mixed to the depth that will solve the problem. For example, surface applications of organic material will have no effect on a subsurface plowpan layer. Similarly, incorporating soil sulfur in the top 6 inches of soil will have little effect on soil pH below that depth. Keep in mind that the active roots of most trees, shrubs, and other perennial plants are concentrated in the upper 1 foot of soil and typically do not grow deeper than about 24 to 36 inches, even in optimal soil conditions.

Evaluating Soil Infiltration and Percolation Rates

Push a large empty coffee or juice can with the bottom removed into the soil until about 2 to 3 inches remain above the surface. This may require hammering on a board placed across the top of the can. Try to push the can straight into the soil. Make sure that the surface of the soil inside the can is undisturbed and free of plant residue. Measure and record the height of the inside of the can from the rim to the soil surface. Fill the can with water. Measure the water depth after 1 hour; this is the soil's infiltration rate, in inches per hour. After all the water has drained from inside the can, repeat the filling and measuring process. The second measurement provides a rough estimate of the soil's percolation rate. An infiltration or percolation rate significantly less than ½ inch per hour is an indication of dense, compacted, or layered soil. Alternatively, you can obtain a rough estimate of a soil's drainage rate by following the process in the section "Estimating Drainage and Depth of Water Penetration" in chapter 4, "Water Management."

Thus, soil problems normally must be modified to this depth in order to provide a long-term remedy. However, a barrier to drainage at 36 inches deep must be addressed because it impedes the removal of water in the active root zone.

Physical Problems in Landscape and Garden Soil

Soil physical problems stem from extremes in textural and structural properties. Extremely clayey soil has poor drainage, reduced aeration, and is difficult to till, whereas soil that is extremely sandy holds minimal amounts of water and nutrients and is not difficult to till. Dense, compacted soil or layers also have poor drainage and low aeration.

Soil compaction is one of the most common and potentially harmful problems that occurs in soil. It can develop in almost any soil type, although some soil is more susceptible than others. Forces holding soil particles together in aggregates may not be strong enough to resist the crushing effect of heavy tillage equipment and excess traffic or the shearing effect that results from working the soil when its moisture content is too high. In the resulting compact soil mass, large pores have collapsed because the structure has been crushed. In the absence of large pores, water penetration becomes very slow. The small pores that are still present may fill slowly with water after irrigation, but they will drain even more slowly because water is held strongly by clay mineral surfaces. Thus, water movement to lower depths is very slow in compacted soil, and little or no air space is left. Feeder roots of most crops will die if deprived of air for only a few hours. Entire root systems will be stunted if compaction is present within the soil zone where a plant's roots normally develop.

Compaction reduces the native bulk density of a soil. When pressure (e.g., foot traffic, mowers, cultivating equipment) is placed on soil, especially wet soil, the pore space is compressed and the volume is reduced, increasing the bulk density. Dense soil layers resulting from human-made soil compaction usually show up within the first foot of the surface, although compression by large grading and tillage equipment may cause some compaction as deep as 2 feet below the soil surface.

Although sandy soil naturally has a higher bulk density than clay soil, coarse-textured sandy soil is more resistant to compaction than the finer-textured clay soil; a compacted sandy soil of the same moisture content as a clay soil may only increase its bulk density to 1.8 grams per cubic centimeter, whereas a clay soil's bulk density may increase to 2.0 grams per cubic centimeter or greater. A surface soil often has a higher bulk density than the subsurface soil because it has been compacted. Especially in hilly areas, a compacted surface leads to lower rates of water holding and infiltration, which can lead to more rainfall runoff and erosion.

Soil layers with very different textures or densities can be created during the grading and filling needed to develop a site. The result is uneven porosity and permeability through the soil profile. Regardless of soil permeability beneath a compacted or texturally different layer, root growth can be restricted at the layer interface, and water will not percolate or infiltrate faster than the limiting rate set by the restricted pore space in the compacted or texturally different layer.

One reason for cultivating soil and core aerating turfgrass and other landscape plantings is to reduce the bulk density of soil to facilitate plant root penetration and water infiltration.

Preventing Soil Structure Breakdown

Structural breakdown of soil is easier to prevent than to cure, so maintaining or improving soil structure is one of the most important aspects of soil management in a landscape or garden area. Although some breakdown of structure within the upper foot of surface soil may be inevitable where land is intensively cultivated, there is frequent foot or equipment traffic, or where

soil has been disturbed during grading and construction, the following recommendations will help prevent or minimize breakdown of soil structure:

- Cultivate or till the soil only when it has a medium moisture content and the soil crumbles easily. Working soil when it is too dry creates large clods or powdery dust, whereas working soil that is too wet creates puddling or packing.
- Till garden soil only when required to turn under organic matter, control weeds, make irrigation furrows, or loosen a volume of soil for planting seeds or transplants.
- Avoid recompaction of freshly loosened, ripped, or plowed soil. The less tillage and traffic after loosening the better.
- Designate traffic areas in landscapes and gardens with paths, and keep foot and equipment traffic over the soil to a minimum, especially when it is very wet.
- Apply organic mulch to bare soil areas around landscape and garden plants.

Tillage stirs the soil and is useful for mixing in manures, fertilizers, crop residues, composts, or other organic materials. It also temporarily loosens the soil and helps control weeds that compete with crops for moisture and plant nutrients. However, frequent cultivation of surface soil does not improve the soil's structure for very long because soil loosened by cultivation usually returns to its original condition after repeated rains or irrigations and the resumption of traffic. Frequent cultivation can damage soil structure because it continually destroys soil aggregates. Organic matter decomposes more rapidly when mixed into the soil, so cultivating reduces soil organic matter content. Thus, it is usually necessary to spade or turn garden soil only once a season. To avoid overtillage, some gardeners maintain long-term planting beds of vegetables or flowers by tilling only a narrow strip on top of the beds to plant seeds or transplants.

Compacted and layered soil

In new plantings, extensive areas of compacted or layered soil can be treated effectively and economically without adding amendments. Physically breaking up the compacted zone or soil layers using deep ripping or large plowing equipment prior to planting is usually satisfactory. In existing plantings, compaction, soil layers, and similar problems can sometimes be remedied with turf aerators, power augers, or water jets that create numerous holes around and in landscape plantings. These techniques are not well proven through research, but limited observations indicate that they can be effective in some situations.

Amending Soil Physical Problems

Soil with poor tilth or structure can sometimes be improved by additions of physical amendments (organic materials or sand). These amendments dilute existing soil particles, which enhances structure (aggregation), alters porosity (improves aeration, drainage, and moisture-holding conditions), and reduces bulk density. It is not practical to try to amend soil around established plants by adding a physical amendment.

If soil structure is poor, the following factors and practices favor the formation of granular structure:

- Bacterial decomposition of organic materials and plant residues produces gums that help to bond soil particles together.
- Planting fibrous-rooted cover crops (grasses) promotes the bonding of soil particles, which yields aggregates with continuous pore spaces between them.
- Cycles of wetting and drying cause swelling and shrinking of soil, generally resulting in improved aggregation.

Sand can be an effective amendment for clayey soil if enough is added so that it is at least 45% of the soil volume to the depth requiring amendment; but sand is expensive and difficult to incorporate adequately. Using too small a volume of sand usually compounds the original problems.

Organic materials (ground bark, compost, manure, sawdust, leaves, lawn clippings, peat moss, etc.) are commonly used to amend soil physical problems. Organic materials are typically much less expensive than sand and have many benefits besides diluting clay particles, but their effects are not permanent because they decompose after a given period. Organic materials are very effective amendments for both clayey and sandy soils when the soil is amended at least 30% by volume (see table 3.13). They reduce the density of clay soil and create aggregation of sandy soil. Adding organic amendments also increases sandy soil's capacity to hold nutrients and water. The material selected should be the same or larger than the granules present in the bulk of the existing soil; note that coarse organic materials last longer in the soil. Organic material should be composted so it is not actively decomposing before use. Nitrogen fertilizer should be incorporated with the organic material at a rate of 1 to 3 pounds of nitrogen per 1,000 square feet of area amended. Research has demonstrated that composted eucalyptus trimmings are generally safe to use as an amendment.

Gypsum (calcium sulfate) can promote soil aggregation and improve water penetration. However, gypsum application is only effective if excessive sodium is responsible for these soil problems. If excessive sodium is not present, adding gypsum will not improve water infiltration or soil structure (see "Amending Chemical Problems in Soil," below).

Amending Chemical Problems in Soil

If a soil's pH is too low, it can be increased (made more alkaline) by adding lime (calcium carbonate, calcium hydroxide, calcium oxide, or dolomite, among others) or wood ashes. If a soil's pH is too high, it can be lowered (made more acidic) by adding sulfur or aluminum sulfate. These materials must be incorporated into the rooting area (root zone) of the soil, a process that can take some time. Lime increases soil pH rather quickly after it has been added to the soil, but sulfur may take several months to lower soil pH.

Acidifying the soil usually takes longer because the conversion of sulfur to acid is mediated by soil microorganisms and depends on temperature and moisture. On established plantings, soil acidification should be done slowly through several small applications of sulfur in order to avoid damaging the root system. It is better to correct the pH before planting. In many areas of California, problems result from soil pH levels that are too high. Incorporating elemental sulfur at 2 to 4 pounds per 100 square feet at a depth of 6 to 8 inches can reduce pH about one point. Beneficial results may not be seen for several months after application. In existing landscapes, apply sulfur in monthly increments of a few ounces per 100 square feet (a few g per 30 sq m), and follow each application with an irrigation.

If pH adjustment is not feasible and high pH limits the availability of iron, zinc, or other nutrients, fertilizer containing a soluble or chelated form of the desired element can be applied to the soil or sprayed on the plant foliage. Follow the product's label directions to avoid overfertilizing and damaging plants.

If sodium concentrations in the soil are high, gypsum (calcium sulfate) and sometimes sulfur are used to reclaim sodic soil. A common misconception is that gypsum lowers soil pH, but its major effect is to improve the infiltration capacity of sodic soil or high-sodium irrigation water. Spreading a total of about 20 pounds per 100 square feet may be effective on new sites. Several months may be required before effects are noticeable. Apply small increments of gypsum to existing landscapes over several months. Large amounts of water must be added to gypsum-treated sodic soil to leach away sodium displaced by gypsum. Irrigate heavily and repeatedly after any gypsum application.

Soluble salts can be reduced by continuous leaching of the soil profile with

successive irrigations. This extra water is called the leaching component, or leaching fraction. Keep high-salt soil evenly moist to minimize damage to plants. Be careful to irrigate fertilizers thoroughly into soil, and do not overfertilize the area. Organic and synthetic mulches on the soil surface can reduce evaporation, which also reduces the accumulation of salts in the root zone.

Managing Lead Contamination of Urban Garden Soil

Home gardeners grow crops that may be subject to lead contamination. In urban areas, lead can build up in soil because of accumulated paint scrapings from buildings that were coated with lead-based paints and from airborne deposition of lead particles (primarily from leaded gasoline). Under normal soil conditions, lead is rather inert because it is readily bound to oxides, clays, and organic matter. However, soil that is deficient in phosphate or has a low pH may contain more soluble lead than plants can take up. When soil lead is taken up by plants it accumulates primarily in root tissue and secondarily in leaf tissue. Most fruits contain little lead.

The following cultural practices are recommended for gardeners who wish to reduce potential lead pollution in their crops:

Locate plantings as far away from streets and roads as is practical, at least 75 feet if possible. Avoid areas around older buildings or where buildings have been demolished.

Maintain soil pH near 7.0 and keep phosphate levels in the higher normal range.

Add as much organic material (compost, manure) as possible.

Wash all produce thoroughly; discard older, outer leaves of leafy vegetables; peel all root crops grown under contaminated conditions.

Avoid growing leafy crops (lettuce, spinach, beet tops, collards, cabbage) near streets or in highly contaminated soil. Fruiting crops, such as tomato, pepper, squash, and melons, can be grown in these situations, however. Wash the fruits before eating.

If high concentrations of soilborne lead are known or suspected, reduce or eliminate possible uptake of lead by removing and replacing topsoil, establishing high raised beds, or growing crops in containers.

Potting Soil and Container Media for Growing Plants

In many situations, it is desirable to grow plants in containers, such as ornamental plants on a patio or entryway, house plants, and vegetable crops where gardening space is limited. Growing a plant in a container is not the same as growing one in soil. This is because the root system is restricted and the physics of the container restricts drainage from the pot. Also, the atmosphere surrounding the pot does not have the same wicking properties as the soil below and around the roots growing in a field. As a result, a given soil in a pot holds more water than that same soil in the field. Common field soil containing silt and clay does not make for good potting media because it does not allow enough media aeration for the roots.

Contrary to popular belief, lining the bottom of a pot with gravel does not improve drainage. It merely reduces the water-holding capacity of the pot and raises the saturated zone in the pot. A good potting media must be well drained for good aeration, yet hold water and nutrients for the plant's use. It supports the plant in the pot and resists decomposition so that frequent repotting is not necessary. Various mixes are available that meet these criteria, or gardeners can make their own. Because of the variability in components used from manufacturer to manufacturer and the lack of information in some packaging, the nutrient content of packaged soil can vary tremendously, and irrigation and fertilization must vary as well.

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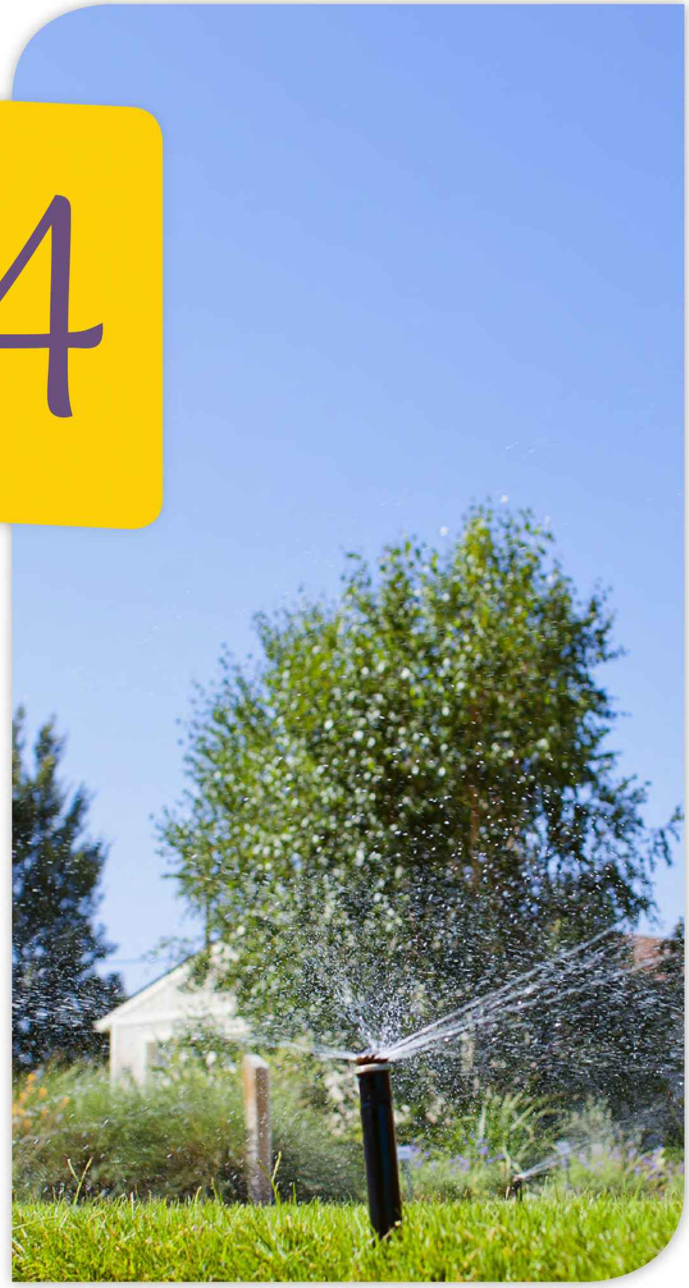
Water Management 4

Janet Hartin and Ben Faber



Learning Objectives

Become familiar with the basic concepts of evapotranspiration (ET) and plant water needs.

Develop an understanding of basic concepts of water movement in soil and plant water availability in different soil types.

Learn how to place plants with similar water needs together and irrigate them effectively.

Understand and apply basic principles of irrigation and water management to maintain optimal plant health, reduce water waste, and protect groundwater and surface water quality.

Learn how to manage drought in California landscapes and gardens.

Water Management

Water is a valuable yet limited resource that is essential for life and required by all land plants in relatively large amounts. In fact, most plants are composed of about 90% water. Water is necessary for photosynthesis and other biochemical processes, cell integrity, and nutrient transport.

Due to prolonged droughts, the uncertainty of future water supplies, and state legislation regulating urban landscape water allocations, it is critical that gardeners implement sound water management practices that ensure the health and vitality of California's urban plantings. Adopting the information and techniques described in this chapter enhances water conservation, reduces water waste, and improves the quality of landscape plantings.

The Plant Water Cycle and Evapotranspiration

Understanding the water cycle of plants is useful for developing effective watering schedules and for recognizing and correcting signs of drought stress (fig. 4.1). Water enters the soil during precipitation (rain, snow, etc.) and irrigation. Water and nutrients in the soil enter plants through the roots and are transported to their shoots via the xylem, the water-conducting portion of the vascular system that extends from the roots to the leaves. Eventually, water is returned to the atmosphere in the form of water vapor, a process called transpiration. Water vapor exits plant leaves through stomata, the tiny pores found in leaf surfaces. Water moves through a plant from a gradient of high water potential in the roots, where water is absorbed, to low water potential in leaves, where transpiration occurs.

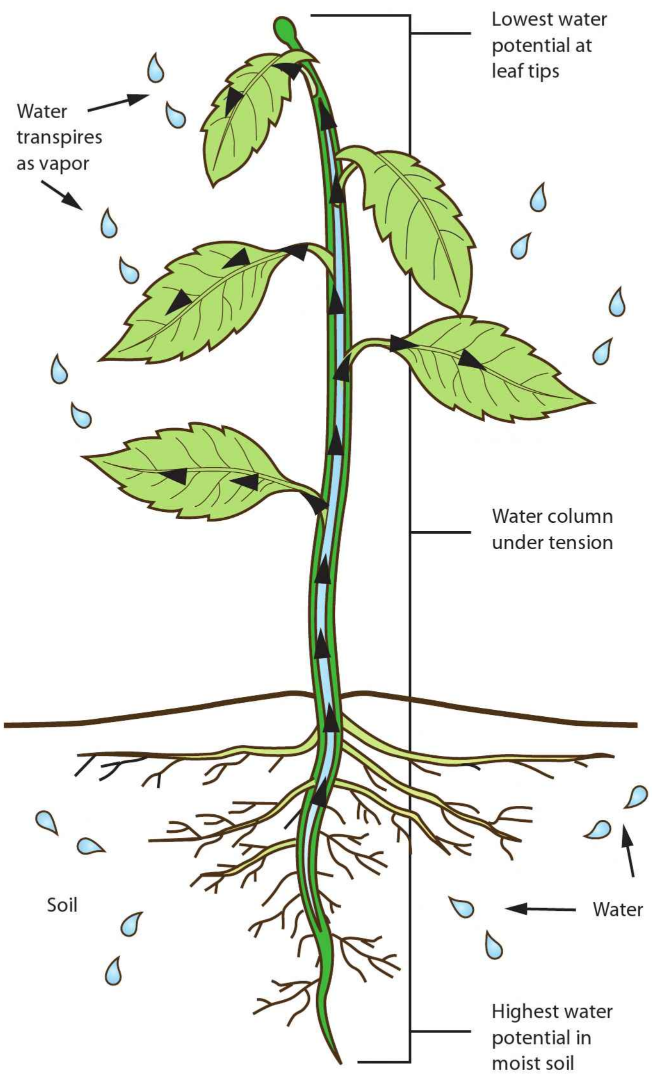


Figure 4.1

The water cycle of a plant. Foliar water loss (transpiration) results from a water potential gradient between the soil water and the air surrounding the leaves. As water transpires, it is replaced by water from the leaf xylem, which draws a column of water up through the entire vascular system, and additional water is taken up by the roots.

But how does water taken up by roots move upward, sometimes 50 to 100 feet or more, to eventually reach leaves of tall trees? The answer lies in the remarkable properties of water molecules themselves. In addition to the strong bonds within a single water molecule, other hydrogen bonds hold oxygen atoms from neighboring water molecules tightly together, producing great tensile strength. Water molecules carried in xylem vessels that are linked to one another form a long, narrow, continuous strand of water that extends downward to root tips. As a water molecule moves into the leaf cell and eventually exits the leaf through transpiration, it pulls the next molecule with it. The energy required for this movement of water through the plant is supplied by the sun. Thus, the primary driving force behind the entire plant water cycle is the sun.

Most of the water taken up by plants is lost to the atmosphere through transpiration. In addition to transpiration, water is also evaporated from the soil. These two processes in combination, evaporation of water from the soil surface and transpiration from the leaf surface, are referred to as evapotranspiration (ET).

While ET rates vary among plant species, the process itself is driven by environmental factors, including sunlight (solar radiation), temperature, relative humidity, and wind speed. Evapotranspiration is expressed in units of depth (inches or millimeters) or volume (gallons or liters) per day, week, month, or year. The rate of ET follows a bell-shaped curve through the year, with the highest rate occurring in midsummer, the lowest in midwinter, and intermediate rates in spring and fall.

Plant Water Use

Evapotranspiration is often referred to as the water use of a plant or a planted area, since it represents water lost by transpiration and evaporation. Well-watered plantings can use enormous amounts of water, most of which is lost to the atmosphere through ET. In fact, on a hot summer day, some well-watered trees can lose 100 gallons of water or more through this process. Most plant species require replacement of a large portion of the water lost for continued normal growth and development. ET rates vary among plant species because of differences in their water-use rates and in their abilities to regulate water loss or avoid tissue damage when water is insufficient.

The values in table 4.1 reflect the average daily water use by 4-inch-tall cool-season turfgrass when soil water is unlimited. The numbers represent what is referred to as ref-

Table 4.1.

AVERAGE DAILY EVAPOTRANSPIRATION (ET) RATES BY LOCATION IN CALIFORNIA (IN/DAY)

Location (see fig. 4.2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Zone 1. North Coast	0.02	0.04	0.06	0.08	0.11	0.12	0.11	0.11	0.09	0.06	0.04	0.02
Zone 2. North Coast Interior Valleys	0.03	0.04	0.08	0.11	0.16	0.20	0.23	0.20	0.15	0.09	0.04	0.02
Zone 3. Northeastern Mountain Valleys	0.02	0.04	0.07	0.12	0.16	0.19	0.26	0.23	0.16	0.09	0.03	0.02
Zone 4. Sacramento Valley	0.04	0.06	0.10	0.15	0.19	0.24	0.26	0.22	0.17	0.11	0.06	0.03
Zone 5. San Joaquin Valley	0.03	0.06	0.10	0.15	0.21	0.25	0.25	0.21	0.16	0.11	0.05	0.02
Zone 6. Central Coast Interior Valleys	0.05	0.08	0.11	0.14	0.18	0.21	0.22	0.19	0.16	0.12	0.08	0.05
Zone 7. Sierra (Tahoe Basin)	—	—	—	0.10	0.13	0.16	0.20	0.17	0.13	0.09	—	—
Zone 8. Central Coast	0.06	0.08	0.10	0.13	0.15	0.16	0.17	0.16	0.13	0.10	0.07	0.05
Zone 9. Southern Coast	0.06	0.09	0.10	0.13	0.14	0.17	0.18	0.18	0.15	0.11	0.09	0.07
Zone 10. Southern Inland Valleys	0.06	0.09	0.11	0.14	0.16	0.20	0.22	0.22	0.17	0.12	0.08	0.06
Zone 11. Southern Deserts	0.09	0.13	0.19	0.25	0.33	0.38	0.37	0.31	0.28	0.20	0.12	0.06

Source: Harris and Coppick 1977, p. 2.
Note: Each of the 11 locations listed is considered a climate zone within the state.

Table 4.2.

AVERAGE SEASONAL EVAPOTRANSPIRATION (ET) RATES BY LOCATION IN CALIFORNIA (INCHES)

Location (see fig. 4.2)	Nov–Mar	Apr–Oct	Annual
Zone 1. North Coast	5.3	20.8	26.1
Zone 2. North Coast Interior Valleys	6.3	34.9	41.2
Zone 3. Northeastern Mountain Valleys	5.1	37.1	42.2
Zone 4. Sacramento Valley	8.5	40.7	49.2
Zone 5. San Joaquin Valley	7.9	40.7	49.0
Zone 6. Central Coast Interior Valleys	10.8	37.5	48.3
Zone 7. Sierra (Tahoe Basin)	—	30.0	—
Zone 8. Central Coast	10.7	30.6	41.3
Zone 9. Southern Coast	12.1	32.3	44.4
Zone 10. Southern Inland Valleys	11.5	37.9	49.4
Zone 11. Southern Deserts	17.7	65.1	82.2

Source: Harris and Coppick 1977, p. 2.
Note: Each of the 11 locations listed is considered a climate zone within the state, as shown in fig. 4.2.

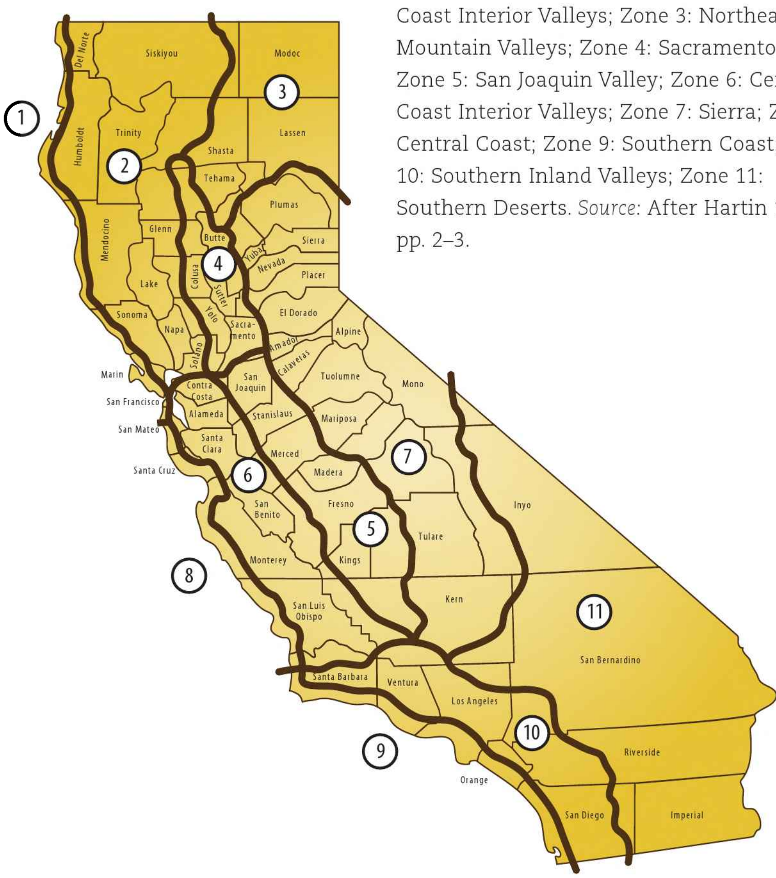


Figure 4.2

Map of California's 11 lawn watering (climate) zones. Zone 1: North Coast; Zone 2: North Coast Interior Valleys; Zone 3: Northeastern Mountain Valleys; Zone 4: Sacramento Valley; Zone 5: San Joaquin Valley; Zone 6: Central Coast Interior Valleys; Zone 7: Sierra; Zone 8: Central Coast; Zone 9: Southern Coast; Zone 10: Southern Inland Valleys; Zone 11: Southern Deserts. *Source:* After Hartin 1991, pp. 2–3.

erence ET rates, which are used by scientists and growers to estimate and compare water use among plant species. Reference ET closely matches the amount of water that many extensive single-species crop plantings use when soil moisture is not limited and the soil surface is at least 80% covered or shaded by plant foliage. It is not the amount of water needed by plants; many plants perform quite well when irrigated below their respective evapotranspiration rate. This is particularly true for most nonturfgrass urban landscape plantings, since reference ET only roughly approximates their water needs.

You can use the map in figure 4.2 and the corresponding ET rates listed in tables 4.1 and 4.2 to estimate the daily, weekly, monthly, and seasonal amounts of soil moisture needed by your plants. In estimating the ET rates for landscape and garden plantings, consider the following:

- The data in tables 4.1 and 4.2 are historical averages. The actual water loss varies somewhat, possibly 10 to 25%, during unusually hot or windy days or unusually cool, cloudy days.
- Plants typically require nearly 100% of ET on a frequent basis after planting until they are established.
- Once they are established, most established landscape plants and turf species can be maintained on considerably less water than the ET rates listed.
- Although certain drought-resistant plants can maintain acceptable performance with reduced amounts of water, many plants considered drought-resistant are “water-spenders” and have daily average ET rates similar to those listed in table 4.1 when water is continuously available.

More detailed information on water needs of specific plant materials and crops is found in this chapter in the section “Water Management Strategies for Specific Plants” and in chapters on specific crops in this book.

Drought Resistance and the Use of Native Plants

Because of California's limited water supply and a desire to conserve urban water, interest has increased over the past several years in the use of drought-resistant plants. Drought resistance reflects the ability of a plant to withstand less-than-optimal water supplies due to adaptive or avoidance mechanisms. Some plants adapt physiologically to sustain important physiological processes with decreased internal water content. Others close stomata to avoid water loss during periods of high temperatures or when soil is dry, or they avoid water stress by producing extensive root systems that have access to additional water. Some possess morphological characteristics that prevent water loss, such as leaves that fold when stressed or silver or gray leaves that reflect light to reduce heat. Some plants avoid water stress by producing thick cuticle layers or waxy surfaces on leaves, while others have leaves with a small surface area, such as needles. While many native plants possess drought-resistant traits and require limited supplemental irrigation once established, many non-native plants also thrive on relatively low amounts of water. Both native and introduced plants require water on a regular basis until established.

Some native plants must receive more water in planned landscapes than they would in their native habitat to maintain an acceptable appearance and performance. Performance expectations and urban conditions (including air pollution and radiated heat) are very different from those in the native habitat of many plants. Adaptation of a plant to urban settings depends on its ability to tolerate urban conditions regardless of its water requirement. The most important consideration when choosing plants is not whether they are native to California but whether they will grow well in a given climate and environment (microclimate). Many non-native plants perform just as well as native plants in urban settings. In fact, some non-native plants thrive in adverse urban microclimates because of breeding and selection programs that have introduced drought-resistant cultivars to the marketplace. Planting a combination of climatically appropriate native and introduced plant materials diversifies the California plant palette, reduces the likelihood of widespread devastation of monoculture plantings by pathogens and insects, and minimizes the need for landscape irrigation.

Soil Water-Holding Capacity and Water Movement in Soil

Soil type (texture) largely determines the water-holding capacity of a soil and its ability to drain adequately. A sandy soil holds only about one-quarter to one-sixth as much total water as a clay soil and must be irrigated more frequently to prevent plant water stress. Table 4.3 shows the amount of water available for plant use in soil of different textures. Fine-textured soil with high clay content often absorbs water more slowly than does coarse-textured sandy soil, but it holds about twice as much water and does not need to be watered as often. However, clay

Table 4.3.

SOIL WATER-HOLDING CHARACTERISTICS FOR TYPICAL SOIL TEXTURE CLASSES AT FIELD CAPACITY

	Inches of water per ft of soil		
Soil texture	Plant-available	Plant-unavailable	Gallons of water per cu ft of soil
sand, fine sand	0.4–1.0	0.2–0.8	0.33–0.66
sandy loam	0.9–1.5	0.9–1.5	0.66–1.00
loam	1.3–2.0	1.4–2.0	1.00–1.25
silt loam	2.0–2.1	2.0–2.4	1.25–1.33
clay loam	1.8–2.1	2.4–2.7	1.25–1.50
clay	1.8–1.9	2.7–3.0	1.33–1.66

Note: Values are approximate; 1 gal of water will cover 1 sq ft of soil 1.6 in deep, or 0.623 gal of water will cover 1 sq ft 1 in deep.

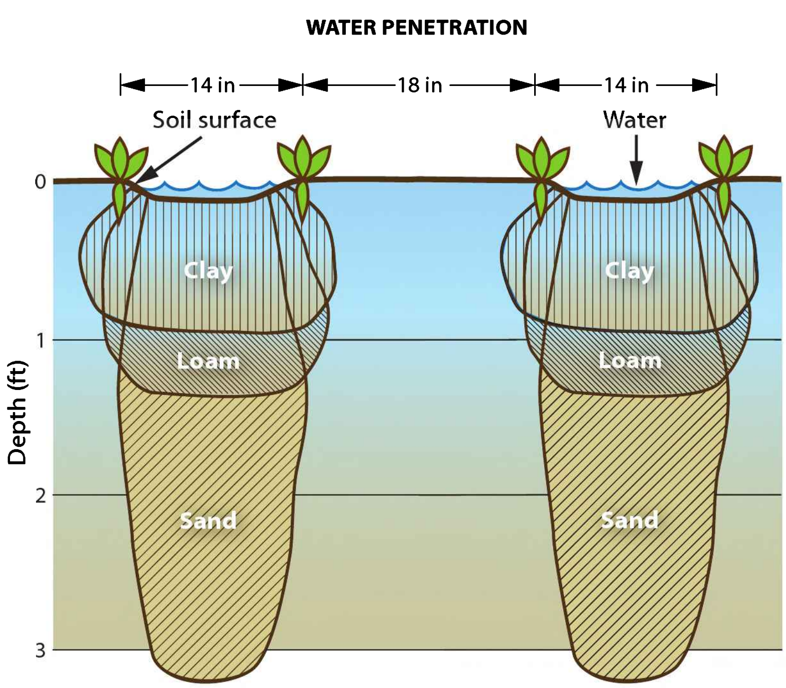
soil drains slower than other soil and is much more likely to become waterlogged and oxygen deprived. A plant growing in clay soil requires just as much water as it would in sandy soil; however, in clay soil, intervals between irrigations should be longer and more water must be applied at each irrigation to wet the soil to a given depth and return it to its water-holding capacity (see fig. 4.3).

Soil structure, the arrangement of soil particles into aggregates of various sizes, shapes, and distinctive features, is also a very important factor determining water and air movement through a soil and ultimately the growth and development of plants. A well-aggregated soil has a wide range of pore sizes, including macropores large enough to allow optimal drainage and root penetration. Macropores also house a wide array of beneficial soil organisms. When native soil is destroyed or scraped away, pore space is reduced, resulting in dense or compacted soil. Urban soil subjected to soil compaction experiences structural degradation as well, resulting in reduced infiltration and a propensity for runoff, erosion, and surface crusting. Even sandy soil can have structural problems when poor subsurface drainage results in runoff and poorly aerated root zones. While poor soil structure cannot be entirely eliminated, minimizing compaction due to equipment and heavy foot traffic and eliminating sodic soil (high sodium relative to a soil's cation exchange capacity) can prevent many problems that would otherwise occur.

The initial entry of water into the soil is called infiltration. The infiltration rate of a soil is the rate at which water enters the soil, expressed as inches or centimeters per hour. Water infiltration is largely determined by soil properties such as organic matter content, structure, and texture. Other factors that influence infiltration are the type of surface cover (plants, mulch, bare soil), slope, surface crusts, and water quality. Water movement within a soil also influences infiltration; water that is not able to move downward through a soil prevents additional water from entering at the soil surface. How readily water moves downward through the soil profile is called permeability, or percolation. Permeable soil conducts water effectively and is not layered or compacted. Dense soil or soil layers that do not conduct water are impermeable. Permeability is largely determined by the texture, structure, organic matter content, presence of horizons that restrict water movement such as cemented or compacted horizons, and abrupt changes in soil texture. Sandy soil and soil that is well structured have relatively higher rates of infiltration and permeability than do clay-rich soil and soil with poor structure. Adding significant amounts of organic matter can improve soil structure and thus improve the infiltration and permeability of some soil. Figure 4.3 depicts the relative penetration of an equal amount of water in three soil types. A given amount of water penetrates much deeper in sandy soil than in loam or clay.

Figure 4.3

Penetration of equal amounts of water in furrows consisting of three soil types. For the three textures depicted, clay holds the greatest amount of available water per foot of depth, and sand holds the least amount of water per foot of depth. *Source:* After Pittenger 1992, p. 20.



Good infiltration and permeability are important because they ensure that water gets to the root systems, that runoff and erosion are prevented, and that air moves efficiently into soil pores. When the application rate of an irrigation system (or rainfall) is greater than the infiltration rate of the soil, or if the soil is saturated, runoff occurs, causing soil erosion and potentially wasting large amounts of water. Conversely, if too much water is applied to a soil that drains freely, water may be lost below the root zone through a process called deep percolation.

Water quality can affect water infiltration. Water that is very pure and low in salts, such as rain and water that comes directly from the Sierra Nevada, can cause even sandy soil to have low infiltration rates. In addition, sodic soil or soft water can also reduce infiltration. In these cases, amendments such as gypsum incorporated in the soil surface can improve water infiltration as long as the sodium salt is leached beneath the root zone by applying large quantities of less-sodic water or rainfall.

Estimating Drainage and Depth of Water Penetration

Adequate soil drainage is an essential part of successful gardening, particularly for plants that do not tolerate constantly wet soil. Poor permeability and slow drainage indicate that the soil might be very dense, compacted, or layered. The steps for formally evaluating soil infiltration and drainage or percolation properties and treating problems that arise are given in chapter 3, "Soil and Fertilizer Management." To roughly estimate the drainage at a planting site, dig a hole about 12 to 18 inches deep and fill it with water. If the soil was dry before filling the hole with water, allow the water to drain, then refill the hole with water and monitor how long it takes to drain. If the soil was at least somewhat moist when digging the hole, proceed to monitor the time it takes for the hole to drain after initially filling it with water. If the hole drains in a few to several hours, the drainage is adequate for most plants. If water remains for 24 hours, the drainage is very slow and will limit the performance and growth of many plants. Slow drainage can be caused by a variety of conditions including

- a soil profile with uniformly low permeability (clay-rich soil)
- a soil with water-restrictive horizons
- claypans
- dense or compacted layers
- cemented horizons
- an abrupt change in texture over a short distance
- a high groundwater table

If drainage is not adequate due to a restrictive horizon where woody plants or other perennials are to be planted, prepare large, unamended planting holes that are 3 to 5 times the diameter of the original root ball but no deeper. Physical soil amendments might also be considered in situations where the profile is uniformly clay rich.

To manage and schedule irrigation effectively, you must know how deep and how long soil remains moist and how deeply water penetrates after an irrigation cycle or series of cycles. A straightforward method to determine soil moisture is to dig a hole and examine the soil. In cases where digging could injure a root zone, pushing a long-handled screwdriver, soil probe, or stiff piece of wire into the soil as far as possible serves as a good indicator of how deeply water has penetrated soil below a planting hole or in a planted area after an irrigation. When the implement reaches dry soil, it will be very difficult to force it down farther; most roots will not grow below that depth if the soil remains dry very long. Be aware that a rock or even a woody root can impede the farther downward movement of a probe or wire, and further investigation may be neces-

sary. Repeated probings after an irrigation will become more difficult over a period of days as plants use soil water. It is time to reirrigate when the probe can be pushed in only about half the average depth of the plant root systems in the area.

Watering Systems for Garden and Landscape Plants

Drip, furrow, and sprinkler systems are useful for watering home plantings. Although no single system is perfect for every situation, some general principles can aid in system selection. Correctly installing and maintaining any watering system are important for the long-term success of the system, the health and development of plantings, and to conserve water. In order for an irrigation system to perform efficiently, follow these general pointers regarding design and installation:

Place irrigation lines supporting irrigation spray heads or emitters parallel to slopes rather than perpendicular to them.

Align spray heads on slopes so they are parallel to the slope angle.

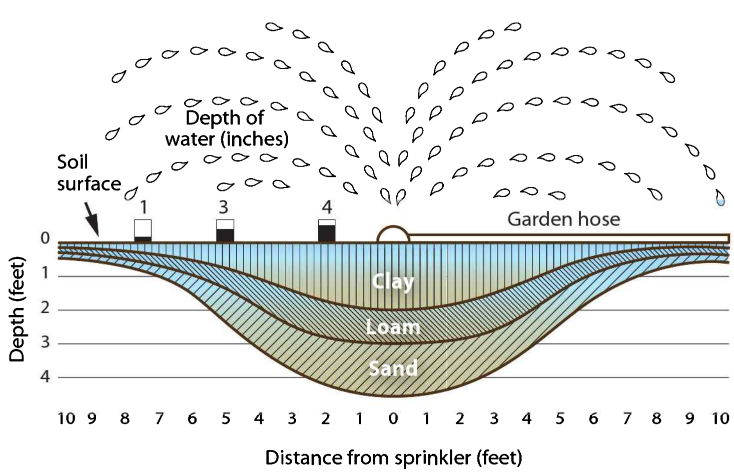
Design the system so that each irrigation valve or station supplies water to plants with similar water needs (hydrozone).

Install heads and emitters of the same make on each irrigation valve or station and replace them with like products when repairs are required.

Space spray heads so that their water output fully overlaps the output of adjacent heads in the system. Figure 4.4 illustrates a typical sprinkler head application pattern and the need for spray overlap among heads in order to achieve uniform water application over an area.

Figure 4.4

Sprinkler placement for overlapping coverage. For sprinkler irrigation, place the sprinklers so the spray of each overlaps with that of each nearby sprinkler. Otherwise, the soil at the outer edges of the sprinkler spray range does not receive adequate water to produce maximum plant growth. *Source:* After Pittenger 1992, p. 21.



Automated Sprinkler Systems

Many advances have been made in irrigation controller technology in recent years. Controllers are now available that provide multiple irrigation programs and cycles, automatically adjust in response to weather conditions, and interface via a personal computer. Minimally, a controller should have the following features:

multicycle, multiprogram capability so that stations (valves) can be set for multiple start times (cycles) and distinct irrigation schedules (programs) can be set for plants with different water needs (for best results, choose a controller that offers three or four cycles and three or four separate programs that stations can be set on)

modular design, so that malfunctioning parts can be easily unplugged and replaced

percentage adjustments in applied water to enable simple changes to be made to the original irrigation program according to weather, a change in plant species, and so on.

a rain switch to temporarily interrupt and hold the current irrigation program in the event of significant rainfall

To use an automatic sprinkler system efficiently over a large area, determine the rate at which the sprinklers apply water

by following step 2 in the "Lawn Watering Guide" in this chapter. For most soil, running the irrigation system until 2 to 3 inches has been applied will provide sufficient irrigation for mature shrubs and trees. The objective for landscape trees and shrubs is to wet the soil to a depth of 1 to 3 feet during each irrigation to promote a deep root system. Several hours of short cycles of irrigation may be required to minimize runoff. Note that most established plants perform best and remain healthiest when the root zone is allowed to dry between waterings to approximately 50% of the soil's water-holding capacity. Refer to the list of approximate rooting depths later in this chapter in the section "Best Management Practices for Irrigation."

Weather-Sensing Controllers

Weather-sensing irrigation controllers, also called smart, or ET, controllers, automatically adjust irrigation in response to weather conditions and offer the potential to simplify schedule changes and conserve water. The controllers can operate any type of system, but their ability to provide year-round irrigation schedules that meet a variety of plant water needs without overirrigating varies widely among brands. Water savings with these devices occurs most commonly in sites that have been significantly overwatered. These controllers typically require a well-trained, experienced horticulturist to set them up correctly. Considerable follow-up monitoring and fine-tuning of the irrigation schedules are normally required to realize their capabilities. A controller of this type should have the same minimum features described above in the section "Automated Sprinkler Systems."

Hose-End Sprinklers

Many Californians do not have automatic watering systems and use hose-end sprinklers to water their lawns and other plantings. The following are some useful ways that landscape plantings can remain attractive and healthy and water waste can be minimized without converting to an expensive automated system:

- Check for leaks between the faucet and hose. A new rubber washer is inexpensive and easy to install.
- Place the sprinkler in a central location surrounded by lawn or landscape planting, avoiding sidewalks, driveways, and structures.
- Keep tree trunks dry! Move the hose-end sprinkler to several locations if necessary to keep trees healthy and to water the lawn or ground cover effectively.
- Check the depth of watering. Wet the soil to the depth of plants' root zones following the rooting depth descriptions in the section "Best Management Practices for Irrigation" in this chapter.
- Water trees and shrubs with a conventional hose on low volume to allow water to soak in slowly and deeply, or use a soaker hose or deep-root irrigator.
- Refer to the "Lawn Watering Guide" below for the total number of minutes to water a lawn each week. To keep sprinkler output consistent during each watering, keep a record of how many turns of the faucet resulted in the preferred volume. Time the number of minutes necessary to water effectively seasonally for future reference.
- Follow the information in the section "Best Management Practices for Irrigation," below.

Furrow Irrigation

Unlike sprinklers, furrow irrigation does not wet foliage, reducing the incidence of some plant diseases. Irrigating with this method is most practical in fruit and vegetable plantings. To furrow-irrigate vegetables, use raised beds.

Drip Irrigation

Drip watering is the frequent, slow application of water to soil through emitters. Emitters are built in or attached to ½-inch -diameter or smaller flexible plastic water delivery lines that carry water to each

plant. A basic drip system has three parts: a control head, which includes a flow control, pressure regulator, and filter; a transmission system of flexible plastic pipes or hose (usually polyethylene tubing); and the emitters. Drip irrigation wets a limited area of soil, only a portion of plants' root systems, reduces water waste between plants, minimizes evaporative losses, and prevents the germination of weed seeds by applying water directly into the root zone. This type of irrigation works well for vegetable gardens, ornamental and fruit trees, shrubs, vines, and outdoor container plants. Soaker hoses are a form of drip irrigation that can be used in small areas, but they do not provide as uniform irrigation as a true drip system.

Drip irrigation offers several advantages to home gardeners. Water is placed more accurately and efficiently in the root zone; water is applied at a slow rate that reduces water loss from runoff; plant foliage remains dry, reducing the potential for disease; dry soil between plants permits work in the garden during irrigation; and little or no management is required while irrigating. Disadvantages include the cost of equipment and installation and possible problems with plugging of small drip orifices, which require routine checking.

Correct installation and operation are important to fully realize the advantages of drip irrigation. For new plantings, one or more emitters must be placed so the root balls and adjacent soil are wetted. On slopes, emitters should be placed slightly upslope from plants. Because drip systems wet a smaller area than do sprinkler or flood irrigation, irrigating mature plants with large root systems requires more frequent irrigations. Although water must be applied daily or on alternate days during the warm season, allow the soil to dry some between waterings. The amount of water needed for most drip applications can usually be supplied by operating the system for several minutes in the spring and a few hours in the summer. However, be certain the watering schedule does not result in water moving below plant root systems. The key to success is to water deep enough during each irrigation to supply adequate water to the root zone. Refer to the preferred rooting depths of various plant types under "Water Plants Deeply and Infrequently," below. As previously mentioned, occasionally determine how deeply the water is penetrating in zones wetted by drip emitters (see "Estimating Drainage and Depth of Water Penetration," above).

Are drip systems really the most efficient form of irrigation? Drip and other irrigation systems are no better than their management. Overirrigation is possible with drip systems because they apply water to a limited soil area, and deep percolation of water below root systems can easily occur with long irrigation run times or too frequent applications. On hilly, uneven terrain, a drip system may be the best choice. Good water filtration and periodic checking for proper operation are needed because if the emitters become clogged by algae, sand, salt, or debris, the system will not perform well.

Basin Irrigation

Perhaps the most efficient irrigation method for tree or shrub plantings is to create a small doughnut-shaped basin around each plant with a small berm of earth placed under its drip line. An exception are trees and shrubs planted in heavy clay soil that may develop anaerobic conditions when this method is used. A second berm is usually built several inches away from the trunk to protect it and the crown roots from becoming waterlogged. When basins are used, they should allow water to drain away from the trunk and be slightly wider than the planting hole. For established plants, the basin should be filled once or twice a week during hot weather. The basin can be rapidly filled with water up to 2 inches deep by using a bubbler, minisprinkler emitters, a garden hose, or similar devices.

Best Management Practices for Irrigation

Homeowners can take several simple steps to conserve water and maintain healthy landscapes and gardens. The following are recommended best management practices for irrigating landscape, garden, and lawn areas efficiently and effectively.

Create Hydrozones

Place plants with similar water requirements together in an irrigation zone (an area watered by the same valve and controller station) to allow them to be watered on the same schedule. This allows the correct amount of water to be applied to individual plants at the correct time, leading to healthier plants and less water waste.

Apply the Right Amount of Water

Overwatering plants is more common than underwatering plants. Research on the water needs of turfgrasses and landscape plants shows that many plants are overirrigated by 20 to 40% or more. Even during summer days with high temperatures, plants may be overwatered. Clay soil, which holds relatively high volumes of water and dries out slowly, is particularly prone to overwatering.

To avoid overwatering or underwatering, you must know how much water your landscape and garden plantings lose through ET. There are simple ways to measure how much water you should provide. If you use a garden hose, turn it on at the force you commonly use and time how many minutes it takes to fill a 1-gallon container. Drip system emitters are usually designed to deliver 1 to 3 gallons per hour. One gallon of water adds 1.6 inches of water over 1 square foot of dry ground and wets that area to a depth of roughly 1.5 inches, depending on soil texture and soil water content when the water is added. Using the same relationship, 0.62 gallons of water applies 1.0 inch of water over 1 square foot. Using these rules of thumb, you can estimate how many gallons or inches of water, and thus how many minutes or hours, it takes to wet your garden to the depth of the root system. If you use a sprinkler system, follow step 2 in the "Lawn Watering Guide" found later in this chapter to determine how much water is being applied at each sprinkling. Alternatively, the volume of water needed or applied can be converted to the depth of water needed or applied with the formula

$$\text{inches of water} = \text{gallons} \div (\text{planted area in sq ft} \times 0.62)$$

Consult the figures in tables 4.1 and 4.2, along with the water needs information for plants found later in this chapter and in other crop chapters, to estimate the right amount of water for your landscape and garden plantings. Also, you can evaluate the effectiveness of irrigation schedules by checking soil moisture content and depth of water penetration with soil probing as discussed in the section "Estimating Drainage and Depth of Water Penetration," above.

Water Plants Deeply and Infrequently

Always wet the soil of established plants to just beyond the depth of their root systems and allow the soil to dry partially between irrigations. This is an excellent way to prevent root rot disease from damaging plants, and watering soil slightly deeper than the depth where the majority of plant roots grow enables plants to access a large reservoir of available water. In desert areas or any place where rainfall is limited, a little extra water must be applied occasionally to leach salts below the root zone. Drip irrigation, which often wets a limited portion of plants' root systems, is often scheduled with short intervals between irrigations in order to keep soil adequately wet and meet plant water needs.

While irrigation systems or practices cannot alter the genetic rooting potential

of a plant, watering deeply (slightly below the root zone) encourages maximal root extension. Follow the guidance on sampling and probing soil in "Estimating Drainage and Depth of Water Penetration," above, to determine whether you are watering deeply enough and at about the correct frequency. Although plants vary in their ultimate rooting depths by species and variety, they can generally be classified into three groups based on where the majority of their root-absorbing activity occurs if there are no limiting factors:

leafy vegetables and annual bedding plants: top 6 inches to 1 foot

cool-season turfgrass and flowering perennials: top 6 inches to 1½ feet

shrubs, trees, ground covers, vines, warm-season turfgrass, and most non-leafy vegetable crops: top 1 to 6 feet

Since actual rooting depths depend on many factors, it is best to sample soil around a given plant to estimate the exact depth of its root system.

Water Early in the Morning

Watering in the early morning under less windy and relatively cool conditions can greatly reduce evaporative water loss and disruption of sprinkler pattern uniformity. However, automated irrigation systems that operate before members of the household are awake should be checked regularly for broken or inoperative components and leaks that may otherwise go undetected. In contrast to sprinklers, drip irrigation systems can be efficiently operated any time of day since they emit water directly to the soil surface.

Avoid Deep Percolation and Runoff

Deep percolation, which is most likely to occur in sandy soil, wastes water due to significant water movement below the root zone of plants. Applying water for shorter periods of time can substantially reduce deep percolation. Since clay soil holds more water than sandy soil and absorbs it more slowly, it is more prone to runoff than to deep percolation. To prevent runoff in heavy soil, apply water at low rates for as long as possible before runoff occurs.

Cycling water in heavy soil, compacted soil, and soil on slopes is often useful. This process involves dividing the water that would normally be applied in a single irrigation into two or more short irrigations several minutes to an hour or so apart while the soil is still moist. Water cycling can be very beneficial on slopes, where the main difficulty is applying enough water to the upper plantings while preventing excess runoff below. Although it is almost impossible to avoid runoff completely, it can be greatly reduced by cycling water.

Apply water every hour for 5 to 10 minutes or until runoff just begins, and repeat the cycle as many times as necessary to fill the soil profile to the depth of plants' root systems. Avoid using high-output fixed-head sprinklers, which apply water faster than it can be absorbed on slopes. Sprinkler outputs of over 1/2 inch per hour often lead to excessive runoff. Choose rotating spray or stream heads that apply water very slowly. Note these must be run twice as long as or longer than conventional spray heads in order to apply the same amount of water. Using drip irrigation for ornamental plantings on slopes is highly recommended since it allows water to be placed in the plant's root zone and avoids runoff. Low-volume micro- and minisprinklers are also excellent for this purpose, since they apply water at a slower rate than conventional lawn sprinklers. Be certain to check the water output rate for specific devices because not all micro- and minisprinklers are low-volume products.

Apply Water Uniformly

An even application of water over a planted area reduces water loss and improves plant health. This is especially important in lawns. When a sprinkler system applies water unevenly, some areas of the lawn receive much less water than most other areas. Brown, drought-stressed

areas of turf will develop, and then many homeowners simply run sprinklers longer to deliver adequate water to the underirrigated areas. This results in wasted water and a higher propensity for disease outbreaks, since many areas in the lawn become overirrigated. A sprinkler system that applies water only half as evenly as a neighbor's system requires twice as much water to ensure that all areas receive enough water (see fig. 4.4). Over the course of a summer, this situation leads to higher water bills as well as a significant amount of wasted water. Regularly conduct can tests (see step 2 in the "Lawn Watering Guide," below) to detect uniformity problems and correct hardware problems such as those listed in table 4.4.

Adjust Irrigation and Reset Irrigation Controllers as Weather and Seasons Change

Irrigation needs of plants change dramatically with seasons and generally follow the ET curve, requiring lower amounts of water in the late fall, winter, and early spring than in the summer. Adjusting irrigation according to seasonal changes in ET rates can decrease water use by up to 50% and enhance plant health. Deciduous plants usually need little if any irrigation during their winter dormancy if rainfall is near normal during this period. Many landscape trees, shrubs, ground covers, and lawns are routinely overwatered during the fall and winter because automatic irrigation controllers are not adjusted to apply less water or irrigate less frequently as ET decreases during this period. Although weather-sensing controllers are available, careful attention is needed to ensure that proper irrigation schedules based on plant water requirements are used for programming (see "Automated Sprinkler Systems," above).

There is also substantial water waste when automatic watering systems are left on during rainy weather. Homeowners planning to be on vacation for an extended period during the rainy season should consider having a rain sensor installed that will automatically shut off their irrigation system when significant rainfall occurs. It is also a good idea to familiarize a neighbor with the controller so the system can be turned off as needed.

Provide Regular Maintenance of Irrigation Systems

Check irrigation systems regularly for physical and operational problems. A simple walkthrough of an area during an irrigation event can uncover possible problems. Table 4.4 lists common irrigation system problems and their solutions. Correcting these problems can reduce water waste by 20 to 50% and can greatly

Table 4.4.

COMMON SPRINKLER PROBLEMS AND THEIR SOLUTIONS

Problem	Solution
broken sprinkler	replace with a sprinkler that applies water at the same rate
unmatched sprinklers	replace with sprinklers that apply water at a common rate
sunken sprinkler risers	raise the sprinklers or replace
crooked sprinklers	straighten to an upright position
turfgrass growing around sprinklers, other plants blocking sprinklers	mow or chemically remove grass, prune or remove plant material
sand or debris plugging sprinklers	flush out sprinklers to remove debris; replace sprinklers as necessary

improve the health of the plants.

If there are brown spots in a lawn or ground cover planting not caused by insects or diseases and a can test (see step 2 in the "Lawn Watering Guide," below) indicates that water is being applied unevenly (low distribution uniformity), operational problems with the irrigation system are likely to blame. An annual can test is recommended for turfgrass irrigation systems.

Apply Mulch

Garden and ornamental plantings benefit from a layer of organic matter (mulch) 2 to 4 inches deep on top of the soil surface. Mulching is one of the most beneficial things a homeowner can do to maintain the health of ornamental plantings. Mulches reduce water evaporation from the soil, minimize weed competition, and can improve soil structure. Intervals between irrigations can be extended somewhat in comparison with a similar planting with bare soil. Mulch should be kept several inches away from tree trunks and should extend outward toward the drip line. Avoid piling mulch around tree trunks. Be certain that each irrigation applies enough water to thoroughly wet the soil below the mulch and into the deepest portion of the root system or slightly deeper. Periodically, the soil under the mulch layer should be checked to make sure that water is penetrating the soil through the mulch.

Amend Soil Extremely High in Sand or Clay

Soil high in clay amended with organic matter will absorb and conduct a greater amount of water more quickly than if left unamended. Sandy soil amended with organic matter holds more water than if unamended, requiring less-frequent irrigation. Follow the guidelines for managing and amending soil found in chapter 3, "Soil and Fertilizer Management."

Water Management Strategies for Specific Plants

Annuals and Perennials

Newly planted beds of annuals and perennials require a relatively frequent and uniform supply of water until roots are established. Once established, irrigation frequency can be reduced. In warm weather, it may be necessary to apply water one or more times daily until plants are established. Henceforth, the interval between irrigations can usually be extended to every 2 or 3 days at about 75 to 100% of ET. Irrigation for established plantings can be one or two times per week during cool weather. Enough water to rewet the root system should be applied during each irrigation.

Vegetables

Generally, vegetable gardens require about 75 to 100% of ET and must be watered regularly throughout their growth cycle in order to perform acceptably. While water requirements are generally similar among vegetable crops, there are slight differences, depending largely on the time of year they are grown, plant size (large plants use more water than small ones), and the variations in length of crops' growing seasons. Prioritize by keeping vegetables that require less water alive during periods of water scarcity, or sacrifice vegetables that you least desire and keep those you prefer, even if they require more water than some of the others.

Irrigate vegetable seeds, seedlings, and recent transplants frequently through establishment to promote a uniform stand of plants and optimum yields. Maintaining moist soil around transplants and seedlings and a uniformly moist seedbed through seed germination help ensure good establishment and a high seed germination rate in the shortest time possible. Supplying water evenly and frequently over the soil surface can prevent soil

crusts from becoming impenetrable.

Maintaining uniform soil moisture is also important for established vegetable plants. Keep in mind that shallow-rooted vegetable crops require more-frequent irrigations than do more deeply rooted crops and that sandy soil promotes deeper rooting than does heavier clay soil. See chapter 13, “Home Vegetable Gardening,” for additional irrigation information and average rooting root depth ranges for specific crops.

Adding a layer of mulch around vegetable plants reduces soil evaporation and weed growth and helps maintain even soil moisture. Drip irrigation, soaker hoses, or careful hand-watering are recommended to conserve water, keep foliage dry to reduce disease problems, and ensure proper water placement in the root zone of vegetables.

Fruit Crops

In order to produce acceptable yields, most fruit crops require 70 to 100% of ET during the growing season. Newly planted fruit crops require frequent, thorough watering, while established plants on most sites perform well with infrequent, deep irrigation. The exceptions are berry crops. It is often useful to irrigate fruit crops with drip or basin irrigation.

Maintaining consistent soil moisture in root zones until trees and vines become established is important, although surface soil may be allowed to dry between waterings without adverse effects during this period. With established fruit crops, water stress can reduce yield and fruit size. It is critical that soil moisture be maintained uniformly during growth flushes and while young fruits are setting. Avoid creating saturated soil conditions. Mulched trees require significantly less water; mulch should be 2 to 4 inches thick and kept several inches away from tree trunks.

Adequate moisture in the root zone must be maintained during extended drought periods. Although many established fruit trees and vines are somewhat drought resistant and can survive on one or two thorough spring and summer waterings, some fruit trees, such as plums and peaches, are prone to insect and disease problems when drought stressed and should be one of the first priorities for watering. See chapters on specific fruit crops for more detailed irrigation information.

Landscape Trees, Shrubs, and Ground Covers

Many commonly used woody landscape plants and nonturf ground covers need only 50 to 60% of ET once they are established. Newly planted trees and shrubs should be frequently irrigated so that the root ball and the soil immediately around it are kept adequately moist during the first season of establishment. They may need to be watered daily the first month or so after planting and usually will need to be watered one to three times per week during the remainder of the establishment period. As they mature, deeper and less-frequent irrigation is preferred to a depth of 1 to 3 feet to encourage deep and structurally strong root systems. Because tree roots spread laterally beyond the drip line of a tree, irrigate outward as well as downward. The objective is to water slowly to ensure that moisture extends into and just below the root zone. Watering mature trees for short periods of time encourages shallow rooting in some situations, which can lead to water stress.

Mature trees should receive enough water to wet most of their root zone every 10 to 14 days in the summer. Do not rely on lawn sprinklers to adequately water landscape trees. Trees growing in lawns can benefit from the water applied to the turfgrass, but depending on how well the turf is being watered, they may need additional deep watering every 4 to 6 weeks or so in the summer. Trees require less-frequent irrigation in the spring and fall and often need little or no irrigation in the winter.

Tree trunks and foliage should be kept dry when watering to discourage waterborne pathogens. Applying a layer of mulch 2 to 4 inches thick starting several inches from the trunk out as close to the drip line as feasible retains soil moisture and prevents weeds. When possible, trees should be watered separately from surrounding plants. A garden hose, micro- or minisprinkler, deep-root irrigator, or drip system works well. Lawns and other plants should be kept at least 1 foot from tree trunks to reduce competition for water and discourage waterborne diseases. This also helps prevent tree damage from string trimmers (weed whips) and lawn mowers.

Make sure trees adjacent to a home, asphalt driveway, sidewalk, or structure receive adequate water. Re-radiated heat can sometimes, but not always, increase the water demand of trees in these settings.

Do not routinely fertilize mature trees. Nitrogen produces new growth flushes, which increases water requirement. Additionally, salts in fertilizer may damage roots if water is insufficient. Avoid unnecessary pruning during a drought because pruning stimulates new growth, requiring additional water.

Lawns

In many cases, more water is applied to lawns than to any other area of a landscape, in part due to poor uniformity (uneven application of water) of sprinkler systems, which wastes significant amounts of water. Cool-season grasses such as tall fescue, annual and perennial ryegrass, bluegrass, and bentgrass require 20 to 30% more water than do warm-season grasses such as bermudagrass, zoysiagrass, and St. Augustinegrass. For optimal performance, cool-season turfgrasses require about 80% of ET and warm-season turfgrasses need about 60% of ET. To remain alive and provide a minimal level of cover, cool-season turfgrasses require about 65% of ET, while warm-season turfgrasses need about 36% of ET. Therefore, significant water conservation can be achieved by converting a lawn from a cool-season grass to a warm-season grass. Careful attention should be given to maintenance and uniformity of the irrigation system used for lawn watering. Below are some additional ways to conserve water in lawns:

- Water early in the morning to reduce evaporation and the effect of wind on sprinkler patterns.
- Water the lawn separately from trees, shrubs, and ground covers.
- Remove thatch in spring if it is more than ½ inch thick. Thatch should not be removed in the heat of summer.
- Control weeds, which compete for water, light, and nutrients.
- Fertilize moderately, applying the low end of recommended rates.
- Aerate as necessary to improve water infiltration. Proper aeration requires removal of plugs. Clay soil often requires aeration two or three times per season.
- Maintain the proper mowing height and remove no more than one-third of the height of the grass each time the lawn is mowed.
- See chapter 11, "Lawns," for more information on lawn watering and maintenance practices.

Lawn watering guide

This lawn watering guide was developed by University of California scientists to increase the health of lawns and reduce water waste. When used correctly, it can reduce the amount of water typically applied to lawns by 20 to 40% or more. This guide promotes accurate irrigation scheduling based on plant water requirements throughout the year in a user-friendly format. Tables 4.5 and 4.6 give the number of minutes to water a lawn each week for every month of the year, based on whether the lawn is a warm-season or cool-season grass and how much water the sprinkler system puts out each hour. The guide incorporates

the ET rates found in table 4.2 with necessary conversions already implemented. The guide specifies the following three simple steps.

Step 1. Determine the type of lawn (cool-season turf stays green year-round, while warm-season grass goes dormant late fall through early spring).

Warm-season: bermudagrass, zoysiagrass, St. Augustinegrass

Cool-season: tall fescue, Kentucky bluegrass, perennial ryegrass

Step 2. Determine the output of the sprinklers by conducting a can test.

Set six or more straight-sided cans of the same type (tuna or cat food cans work well) on the lawn between the sprinkler heads. Run the sprinklers for 20 minutes and measure the water in each can with a ruler. Determine the average depth in inches of water in each can. Multiply by 3 to determine the sprinkler output in inches per hour.

If a difference of more than 15 to 20% exists among the depths of water in individual cans, significant problems with the irrigation system must be corrected to improve the evenness (uniformity) of the water application. Table 4.4 gives some common problems with sprinkler irrigation systems and suggested remedies.

Step 3. Determine how long to water the lawn each week.

Locate the appropriate lawn watering zone in figure 4.2. Tables 4.5 and 4.6 give the total number of minutes to water each week based on the location (see fig. 4.2), the lawn type (step 1, above), and the information obtained from the sprinkler output (step 2, above).

Additional minutes (more water) may be needed if the sprinkler system does not apply water uniformly, as determined in step 2 above.

Knowing when and how long to water is just as important as knowing how much water to apply. Applying too much water at one time can result in substantial water loss from runoff or deep percolation. To determine how long to water, turn on the irrigation system at the same time of day it is normally operated (preferably early morning) and measure the amount of time it takes for runoff to begin. Divide this number into the weekly number of minutes obtained from the lawn watering guide to determine how many times to water. Two examples of using the lawn watering guide, based on lawn type, location, season, sprinkler output, and length of time until runoff begins, are shown below.

Example 1. In Claremont (Zone 10), a bermudagrass lawn (warm-season turf) has an irrigation system with a sprinkler output of 1 inch per hour, and runoff occurs after 15 minutes. During May, the lawn should be watered for 15 minutes four times per week (60 minutes per week).

Example 2. In Santa Clara (Zone 6), the irrigation system of a tall fescue lawn (cool-season turf) has a sprinkler output of 1.5 inches per hour, and runoff occurs after 10 minutes. During March, the lawn should be watered for 10 minutes three times per week (30 minutes per week).

Keeping Plantings Alive under Drought or Water Restrictions

Plants that do not receive enough water due to drought or governmental restrictions aimed at water conservation eventually show signs of water stress. Although plants vary in the amount of water they require for optimal growth and development, most exhibit characteristic symptoms when they are in need of water. Because water-stressed plants must be watered at an early stage of water deficit to prevent irreversible damage, it is crucial to check plants regularly for symptoms of drought, preferably during the afternoon, when symptoms are most evident. Common symptoms include

Table 4.5.

LAWN WATERING GUIDE FOR NORTHERN AND CENTRAL CALIFORNIA (MINUTES TO WATER EACH WEEK) (FOR LOCATION OF ZONES, SEE FIG. 4.2)

Zone 1. North Coast

COOL-SEASON TURF
Warm-Season Turf—Not Recommended

	Hourly sprinkler output (in)			
Month	**0.5**	**1.0**	**1.5**	**2.0**
Jan	15	7	5	4
Feb	36	18	12	9
Mar	55	27	18	14
Apr	67	34	22	17
May	88	44	29	22
Jun	97	48	32	24
Jul	95	47	32	24
Aug	90	45	30	23
Sep	76	38	25	19
Oct	48	24	16	12
Nov	32	16	11	8
Dec	21	11	7	5

Zone 3. Northeastern Mountain Valleys

COOL-SEASON TURF
Warm-Season Turf—Not Recommended

	Hourly sprinkler output (in)			
Month	**0.5**	**1.0**	**1.5**	**2.0**
Jan	17	8	6	4
Feb	34	17	11	8
Mar	59	29	20	15
Apr	101	50	34	25
May	134	67	45	34
Jun	168	84	56	42
Jul	210	105	70	53
Aug	176	88	59	44
Sep	126	63	42	32
Oct	76	38	25	19
Nov	25	13	9	6
Dec	17	9	6	4

Zone 2. North Coast Interior Valleys

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	**0.5**	**1.0**	**1.5**	**2.0**
Jan	19	9	6	5
Feb	32	16	11	8
Mar	50	25	17	13
Apr	69	35	23	17
May	101	50	34	25
Jun	126	63	42	32
Jul	132	66	44	33
Aug	120	60	40	30
Sep	95	47	32	24
Oct	57	28	19	14
Nov	25	13	8	6
Dec	13	6	4	3

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	**0.5**	**1.0**	**1.5**	**2.0**
Jan	25	13	8	6
Feb	42	21	14	11
Mar	67	34	22	17
Apr	92	46	31	23
May	134	67	45	34
Jun	168	84	56	42
Jul	176	88	59	44
Aug	160	80	53	40
Sep	126	63	42	32
Oct	76	38	25	19
Nov	34	17	11	8
Dec	17	8	6	4

Zone 4. Sacramento Valley

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	**0.5**	**1.0**	**1.5**	**2.0**
Jan	19	9	6	5
Feb	44	22	15	11
Mar	69	35	23	17
Apr	101	50	34	25
May	126	63	42	32
Jun	158	79	53	39
Jul	164	82	55	41
Aug	145	72	48	36
Sep	113	57	38	28
Oct	82	41	27	20
Nov	38	19	13	9
Dec	19	9	6	5

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	**0.5**	**1.0**	**1.5**	**2.0**
Jan	25	13	8	6
Feb	59	29	20	15
Mar	92	46	31	23
Apr	134	67	45	34
May	168	84	56	42
Jun	210	105	70	53
Jul	218	109	73	55
Aug	193	97	67	78
Sep	151	76	50	38
Oct	109	55	36	27
Nov	50	25	17	13
Dec	25	13	8	6

Zone 5. San Joaquin Valley

WARM-SEASON TURF

Month	Hourly sprinkler output (in)			
	0.5	1.0	1.5	2.0
Jan	19	9	6	5
Feb	38	19	13	9
Mar	69	35	23	17
Apr	101	50	34	25
May	132	66	44	33
Jun	164	82	55	41
Jul	170	85	57	43
Aug	145	72	48	36
Sep	113	57	38	28
Oct	69	35	23	17
Nov	32	16	11	8
Dec	13	6	4	3

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	25	13	8	6
Feb	50	25	17	13
Mar	92	46	31	23
Apr	134	67	45	34
May	176	88	59	44
Jun	218	109	73	55
Jul	227	113	76	57
Aug	193	97	64	48
Sep	151	76	50	38
Oct	92	46	31	23
Nov	42	21	14	11
Dec	17	8	6	4

Zone 6. Central Coast Interior Valleys

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	32	16	11	8
Feb	44	22	15	11
Mar	69	35	23	17
Apr	95	47	32	24
May	113	57	38	28
Jun	113	57	38	28
Jul	132	66	44	33
Aug	126	63	42	32
Sep	107	54	36	27
Oct	76	38	25	19
Nov	44	22	15	11
Dec	32	16	11	8

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	42	21	14	11
Feb	59	29	20	15
Mar	92	46	30	23
Apr	126	63	42	32
May	151	76	50	38
Jun	151	76	50	38
Jul	176	88	59	44
Aug	168	84	56	42
Sep	126	71	48	36
Oct	143	71	48	36
Nov	59	29	20	15
Dec	42	21	14	11

Zone 7. Sierra

COOL-SEASON TURF

Warm-Season Turf—Not Recommended

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	31	15	10	8
Feb	43	22	14	11
Mar	79	39	26	20
Apr	124	62	41	31
May	164	82	55	41
Jun	207	103	69	52
Jul	231	115	77	58
Aug	198	99	66	50
Sep	141	70	47	35
Oct	96	48	32	24
Nov	40	20	13	10
Dec	20	10	7	5

Zone 8. Central Coast

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	38	19	13	9
Feb	50	25	17	13
Mar	63	32	21	16
Apr	88	44	29	22
May	101	50	34	25
Jun	113	57	38	28
Jul	95	47	32	24
Aug	113	57	38	28
Sep	95	47	32	24
Oct	69	35	23	17
Nov	50	25	19	13
Dec	38	19	13	9

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	50	25	17	13
Feb	67	34	22	17
Mar	84	42	28	21
Apr	118	59	39	29
May	134	67	45	34
Jun	151	76	50	38
Jul	126	63	42	32
Aug	151	76	50	38
Sep	126	63	42	32
Oct	92	46	31	23
Nov	67	34	22	17
Dec	50	25	17	13

Source: Hartin et al. 2002.
Note: If runoff or brown spots occur with weekly watering, divide the weekly total by 2, 3, or 4 to water two, three, or four times a week for fewer minutes. Desert areas especially need several shorter waterings. Watering should be suspended during any period when rainfall equals or exceeds the ET rates found in tables 4.1 and 4.2.

Table 4.6.

LAWN WATERING GUIDE FOR SOUTHERN CALIFORNIA (MINUTES TO WATER EACH WEEK) (FOR LOCATION OF ZONES, SEE FIG. 4.2)

Zone 9. Southern Coast

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	44	22	15	11
Feb	57	28	19	14
Mar	63	32	21	16
Apr	76	38	25	19
May	88	44	29	22
Jun	95	47	32	24
Jul	107	54	36	27
Aug	95	47	32	24
Sep	82	41	27	20
Oct	69	35	23	17
Nov	50	25	17	13
Dec	38	19	13	9

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	59	29	20	15
Feb	76	38	25	19
Mar	84	42	28	21
Apr	101	50	34	25
May	118	59	39	29
Jun	126	63	42	32
Jul	143	71	48	36
Aug	126	63	42	32
Sep	109	55	36	27
Oct	92	46	31	23
Nov	67	34	22	17
Dec	50	25	17	13

Zone 10. Southern Inland Valleys

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	42	21	14	10
Feb	57	28	19	14
Mar	80	40	27	20
Apr	96	48	32	24
May	119	60	40	29
Jun	144	72	48	36
Jul	165	83	55	41
Aug	155	77	52	39
Sep	124	62	41	31
Oct	88	44	29	22
Nov	54	27	16	14
Dec	42	21	14	10

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	56	28	19	14
Feb	75	38	25	19
Mar	106	53	35	27
Apr	128	64	43	32
May	159	80	53	40
Jun	193	96	64	48
Jul	221	110	74	55
Aug	207	103	69	52
Sep	165	82	55	42
Oct	117	59	39	29
Nov	73	36	24	18
Dec	55	28	19	14

Zone 11. Southern Deserts

WARM-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	54	27	18	14
Feb	75	38	25	19
Mar	121	61	40	30
Apr	165	83	55	41
May	211	106	70	53
Jun	243	121	81	61
Jul	251	126	84	63
Aug	218	109	73	54
Sep	180	90	60	45
Oct	121	61	40	30
Nov	69	35	23	17
Dec	43	22	14	11

COOL-SEASON TURF

	Hourly sprinkler output (in)			
Month	0.5	1.0	1.5	2.0
Jan	65	32	22	17
Feb	90	46	30	23
Mar	145	73	48	36
Apr	198	100	66	49
May	253	127	84	64
Jun	292	145	97	73
Jul	301	151	101	76
Aug	262	131	88	65
Sep	216	108	72	54
Oct	145	73	48	36
Nov	83	42	28	20
Dec	52	26	17	13

Source: Hartin et al. 2002.
Note: If runoff or brown spots occur with weekly watering, divide the weekly total by 2, 3, or 4 to water two, three, or four times a week for fewer minutes. Desert areas especially need several shorter waterings. Watering should be suspended during any period when rainfall equals or exceeds the ET rates found in tables 4.2 and 4.3.

- wilting or drooping leaves that do not return to normal by evening
- curled or chlorotic (yellow) leaves that may fold or drop, or foliage that becomes grayish and loses its green luster
- new leaves that are smaller than normal
- lawn grasses that retain a footprint for several minutes

Temporary wilting may occur on hot, dry days in plants that have adequate soil moisture. Some broadleaf ornamentals, bedding plants, and vegetables such as cucumber and squash may wilt during the day because their roots cannot absorb water fast enough to replace transpirational water loss from leaves. This process is referred to as physiological wilt. Fortunately, afflicted plants generally recover during the evening. Adding additional water during the day is not necessary and, in some cases, may prove detrimental by depriving roots of oxygen.

Other causes of symptoms mimicking water stress are vascular diseases such as those caused by *Verticillium* or *Fusarium* fungi, or other pests and diseases that damage plant vascular or root systems. Checking soil moisture in the root zone of the plant is sometimes necessary to determine whether the wilting is actually due to inadequate moisture. If the soil is moist or the plant does not respond to watering within 24 hours, suspect other causes of wilting.

If plants are water stressed and it is not possible to apply an optimal amount of water due to regulatory water limitations, most mature perennial plants can survive short periods on smaller amounts of water, particularly if adequate water is supplied during other seasons of the year. Although mature trees can often survive one season with only one or two deep waterings during the spring and summer, two seasons without enough water can result in severe drought stress and even death. Drought-stressed trees can be more prone to damage from diseases and insects. One or two irrigations to 1 to 2 feet deep and outward to the drip line may be enough to keep landscape trees alive through a season. Using a garden hose for this purpose makes wise use of limited water.

Keeping fruit and nut trees alive during severe water shortages is also possible, although crop production will probably be greatly reduced or stop. To produce a good crop, deciduous fruit and nut trees need adequate water in their root zones continuously from bloom until harvest. Citrus trees need adequate soil moisture during spring to set fruit and steady water in summer and fall to produce acceptable size, numbers, and quality of fruit. However, fruit and nut trees can be kept alive with a few early-season water applications, but they may not set much fruit.

Most established shrubs can survive long periods of dry soil. Thorough spring watering and one or two thorough waterings in the summer keep most well-established shrubs alive for at least one season.

Established warm-season lawns, such as bermudagrass, go dormant in summer if water is inadequate but often recover. They generally survive on as little as 20 to 30% of their optimal water requirement for moderate periods of time. Cool-season grasses, such as tall fescue, require 20 to 30% more water than warm-season grasses and show drought symptoms earlier. They will go dormant and thin out with prolonged water stress. Their recovery is directly related to how long they were drought stressed.

Ground covers often survive on about half the amount of water they would receive under optimal conditions, although some dieback may occur. To avoid serious drought stress, they should be watered at least every 3 to 6 weeks from April through September, depending on location and soil conditions.

Large plantings of vegetables and bedding annuals are difficult to maintain during a drought. It may be necessary to sacrifice these plantings or reduce their size to allow available water to be directed

to more valued or more expensive long-term perennial plantings.

Use of Graywater in Urban Landscapes

Definition and Overview

The use of graywater (also "gray water," "greywater," or "grey water") to irrigate landscape plants is increasing throughout the United States, particularly in California and other arid states. In the United States, *graywater* most often refers to wastewater that originates from residential clothes washers, bathtubs, showers, and sinks, and it excludes wastewater generated from kitchen sinks, dishwashers, and toilets (black water).

In California, under Health and Safety Code § 17922.12, *graywater* is defined as "untreated wastewater that has not been contaminated by any toilet discharge, has not been affected by infectious, contaminated, or unhealthy bodily wastes, and does not present a threat from contamination by unhealthful processing, manufacturing, or operating wastes. Graywater includes, but is not limited to, wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines, and laundry tubs, but does not include wastewater from kitchen sinks or dishwashers."

A permit is no longer required for the installation of the following single-family or two-family residential graywater irrigation systems if other conditions under California Department of Housing and Community Development (HCD) § 1603A1.1 are met: a simple clothes washing graywater system, as long as it does not require cutting of the existing plumbing piping.

All other systems require a construction permit prior to erection, retrofitting, construction and installation as stated in the actual code. The full text of these standards can be viewed at the HCD Division of Codes and Standards website, hcd.ca.gov/codes. Because these regulations may change at any time, always check with HCD and local enforcement agencies before developing plans for or installing a graywater system. Cities and counties can impose stricter guidelines than the state, so homeowners interested in installing graywater systems should contact their local jurisdiction for specific regulations concerning graywater handling and use.

Laundry-to-landscape graywater systems are relatively simple to install and are inexpensive. The hose exiting the clothes washing machine is attached to a valve that separates graywater from water destined for the sewer. The graywater is diverted through a 1-inch main irrigation line with ½-inch tubing outlets placed throughout the landscape terminating in a valve box set in what is termed a mulch basin that surrounds plants being watered (see below). The washing machine pump distributes water directly to the landscape with no filter. A vacuum break or backflow prevention device may also be needed. Keep in mind that salt-free and boron-free liquid laundry detergents should be used for irrigating the landscape. In addition, chlorine bleach should be avoided.

All laundry-to-landscape systems not requiring a permit are required to

- be equipped to direct flow back to the sewer (e.g., a three-way valve)
- have valves and direction of graywater flow clearly labeled
- supply graywater to landscape plantings only on the homeowner's property
- include an operation and maintenance manual
- discharge graywater underneath a 2-inch cover of mulch, plastic shield, or stone covering

Laundry-to-landscape systems must not

- use water contaminated by diapers and human waste
- contain hazardous chemicals from oily rags, photo labs, car parts, and so on
- create pooling of standing water or an open tub
- create water pollution through runoff or deep percolation of graywater into groundwater and surface waters
- include a pump (other than a washing machine internal pump)

connect to any potable water supply

affect or alter electrical, plumbing, mechanical, or structural components of the home

Mulch basins receive and distribute graywater to plant root zones and are constructed by removing several inches of soil and replacing it with coarse organic mulch. These basins are established in bed areas or near plants so that the graywater reaches plant root systems. They must be sized correctly to prevent surface ponding. Sizing depends mainly on soil texture (sandy loam, clay loam, etc.). Graywater percolates quickly through sandy soil, requiring minimal mulch. In slower-percolating clay loam soil, a larger mulch basin is required around the valve box to prevent graywater pondage. Large wood chip mulch is more durable and longer lasting than smaller wood chip mulches or shredded fiber.

Applying graywater through a drip irrigation system is not generally recommended. Drip emitters can quickly clog with hair and other graywater products and require a filter and regular filter cleaning. A drip system for this use also requires a backflow preventer to ensure that potable water is not contaminated and a pump and controllers to ensure that water flows through the emitters. These systems are expensive and require regular maintenance.

Benefits and Risks

Using graywater to irrigate landscape plants can conserve water and electricity and reduce water bills by recycling water otherwise destined for a wastewater treatment plant. Since an estimated 30 to 50% of home water use produces graywater, significant savings can be realized by reusing this source of nonpotable water to irrigate landscape plants. A typical household (2.6 people) produces an average of 90 gallons of graywater each day. While most graywater systems will not supply enough irrigation water to irrigate an entire traditionally landscaped yard, most can supply one-half to three-quarters of the water required by a drip-irrigated water-efficient landscape with limited or no turf.

The potential risks should be carefully evaluated before deciding whether to install a graywater recycling system. Graywater varies substantially in quality and potential risks from site to site. Many household cleaning products, as well as many shampoos, soaps, and detergents, contain dyes, bleach, chlorine, sodium, boron, and phosphate, which can pose significant human and environmental health concerns and can injure and even kill plants at high dosages over a short period or smaller dosages over a longer period.

Impact of Graywater on Human Health

Because of the recent changes regarding graywater reuse under California and other state statutes, research pertaining to the long-term impacts and risks of graywater reuse on human health, plant health, soil chemistry, and groundwater and surface water quality is very limited. A review of current research-based information follows.

Research examining the microbial constituency of graywater indicates that direct contact with graywater can pose a health risk to humans. Pathogens can enter graywater through food sources in the kitchen, which is why use of graywater generated from kitchen sinks and dishwashers is not recommended. Also, because pathogens can enter graywater through fecal matter, avoid water contaminated by dirty diapers. Pathogens posing the greatest concern in graywater include bacteria such as enterotoxigenic *Escherichia coli*, *Salmonella* spp., *Shigella* spp., *Vibrio cholera*, *Campylobacter* spp., and *Legionella* spp.; protozoans such as *Giardia* spp. and *Cryptosporidium* spp.; and viruses such as enteroviruses, hepatitis A, rotavirus, and Norwalk virus.

Graywater should not be applied

directly to edible plant parts or root crops. To be safe, it should be applied only to nonedible ornamental plants. Avoid splashing graywater on neighboring edible plants. Graywater should not be applied through sprinkler systems, since droplets containing harmful microbes can become suspended in the air and breathed.

Impact of Graywater on Soil Chemistry and Water Quality

Limited research exists that addresses the fate of microorganisms found in graywater and their impact on indigenous soil microorganisms, soil chemistry, and water quality. Infiltration through soil, rock, and other materials that serve as filters can significantly diminish the threat of water pollution from graywater use. Unfiltered graywater accumulating in surface water and graywater seepage into nearby wells can diminish water quality.

Impact of Graywater on Plant Health

Because graywater is often rich in nutrients required for plant growth, ornamental plants may benefit from its use. However, numerous studies indicate that graywater may contain significant levels of sodium and other salts harmful to plants, particularly from powdered laundry detergents. Since ornamental plants vary dramatically in their sensitivity to potentially harmful salts found in graywater, care must be taken when plants are irrigated with graywater that is high in salts, particularly over a long-term basis (see Wu and Dodge 2005).

In general, evergreen trees are more salt sensitive than deciduous trees. Very little is known regarding the impact of graywater use on annual bedding plants.

More research is needed on the impact of graywater on plant health since the chemical composition of graywater is different than that of treated wastewater and surfactants are widely used in household cleaning products.

Regardless of what graywater system is chosen, the following precautions should always be taken:

Carefully label all valves and pipes associated with your graywater system and prevent backflow.

Do not store graywater more than 24 hours.

Wear gloves and do not come into direct contact with graywater.

Do not let graywater pool or run off the soil surface or come into contact with well water.

Do not irrigate edibles with groundwater or allow it to splash onto neighboring edible plants.

Do not irrigate turfgrass or ground cover areas with graywater, since potentially harmful microorganisms can remain on the surface. Do not use graywater contaminated with human waste, infectious disease organisms, grease, paint residue, gasoline, solvents, or other chemicals found in household and industrial products.

Keep the graywater system simple and avoid systems requiring heavy upkeep and maintenance. Contact a professional with experience designing and installing graywater systems if you lack the specific knowledge or time to undertake the project yourself.

Protecting Water Quality in Urban Landscapes

Surface water and groundwater contamination from pesticides, fertilizers, and other chemicals used in and around California landscapes can lead to polluted creeks, rivers, and oceans, largely during runoff from heavy rain and poor irrigation practices. Indiscriminate use and disposal of these garden products and household chemicals can also threaten aquatic life. A recent National Water Quality Inventory indicated that runoff in urban areas is a leading source of water quality degradation.

Best Management Practices to Prevent and Reduce Water Pollution in Urban Landscapes

Do not apply water faster than the soil can take it up (common in clay-rich soil); make sure that you are not deep-percolating applied water into groundwater below the root zone (common in sand-rich soil).

Except at tree planting sites, apply amendments to soil that is extremely high in clay or sand to help reduce run-off and deep percolation.

Keep pet wastes and pesticide-treated plant debris out of gutters and storm drains.

Use integrated pest management practices, which stress insect, disease, and weed prevention rather than the use of pesticides.

Do not apply more fertilizer than is absolutely needed; use fertilizers containing slow-release or water-insoluble sources of nitrogen.

Dispose of used oil, paints, and other garden and household chemicals using your local jurisdiction's hazardous waste collection point and clean up spilled oil and gasoline immediately.

Prevent soil erosion by using mulch and dense plantings of ground covers.

Use household detergents and cleaners low in phosphorus and carefully follow the guidelines under "Use of Graywater in Urban Landscapes," above, when recycling household water.

Irrigating home landscape and edible plantings based on plant water requirements and soil conditions coupled with the use of other recommended management practices helps ensure healthy, attractive and productive plantings that do not threaten water quality or endanger future water supplies. Following the recommendations in this chapter and other chapters in this handbook will help readers green their own landscapes while protecting the environment for the use and enjoyment of future generations.

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Plant Propagation

5

Pamela M. Geisel

Learning Objectives

Understand the basic principles of sexual and asexual plant propagation.

Learn how to store and germinate seeds.

Learn how to germinate spores of ferns.

Learn how to transplant and harden off young seedlings and plants.

Know how to propagate a plant asexually from a stem, leaf, root cutting, layering, or division.

Learn the basics of grafting, budding, and home tissue culture techniques.

Plant Propagation

Plant propagation is the process of increasing the numbers of a given species. There are two types of propagation: sexual and asexual. Sexual propagation in higher plants, which is also known as sexual reproduction, involves the floral parts of the plant. The egg (the female gamete contained in the ovary of the flower) and the sperm (the male gamete contained in the pollen) unite in a process that can mirror sexual reproduction in human beings by drawing from the gene pool of two parents (flowers) to create a new individual. Unlike sexual reproduction in humans, however, the process in plants may involve only one parent, because some flowers contain both male and female sex organs and can self-reproduce. Asexual propagation uses the vegetative or nonfloral parts of the plant (stems, leaves, or roots) to generate a new plant. Propagation by asexual methods occurs very readily in higher plants. Genetically, the asexually propagated new individual plant is identical to its parent stem, leaf, or root and could be called a clone of its parent. Typically, greater genetic diversity exists in plants propagated by sexual methods. The discussion of plant propagation that follows is adapted from materials presented in Frey 1993.

Both sexual and asexual propagation have advantages. Sexual propagation may be less expensive and quicker than other methods; it may be the only way to obtain new cultivars and maintain hybrid vigor and a greater genetic diversity within a species. In certain species, it is the only practical method of propagation, and it can reduce the transmission of certain diseases. The primary advantage of asexual propagation is that it perpetuates favorable characteristics of the parent plant as closely as possible. In some species, it may also be easier and faster, and it may be the only way to reproduce some cultivars.

Sexual Propagation

Sexual propagation involves the union of the sperm, contained in the pollen grains, with the egg, located in the female plant parts (the ovary and ovules), which together produce a zygote that later divides into many cells to form the embryo of the seed. Seeds, which are the products of sexual propagation in plants, comprise three parts: the outer seed coat that protects the seed; the endosperm, a food reserve tissue; and the embryo, which is actually a developing young plant in a relatively dormant state. When a mature seed is placed in a favorable environment, it will germinate (begin active growth), develop into a seedling, and later become a mature plant.

Obtaining and Storing Quality Seeds

High-quality plants begin with high-quality seeds purchased from a reliable dealer. Select cultivars adapted to your area that provide the size, color, and growth habit desired. Many new vegetable and flower cultivars are hybrids, which are more expensive than open-pollinated (nonhybrid) types, but hybrid plants usually have more vigor, more uniformity, and better productivity than nonhybrids and sometimes possess resistance to specific diseases or other unique characteristics. However, some people prefer open-pollinated seeds in order to maintain genetic diversity within a species or population. These cultivars are capable of producing seeds that reproduce plants like the parent plant for several generations. Heirloom cultivars are open-pollinated, but not all open-pollinated cultivars are considered heirloom. See chapter 13, "Home Vegetable Gardening," for more discussion about open-pollinated and heirloom vegetable cultivars.

Although some seeds keep for several years if stored properly, it is advisable to purchase only enough for the current year's use. Even high-quality seeds may contain minute amounts of noncrop seeds, but they will almost always be void of noxious weed seeds. Printing on the seed packet must note the year for which the seeds were packaged, the germination percentage expected, and any chemical seed treatments. If seeds are obtained well in advance of the actual sowing date, or if they are stored as surplus, keep them in a cool, dry place. Two factors shorten seed life: high moisture and high temperature. Each 1% decrease in seed moisture and each 10°F drop in storage temperature doubles the life of seeds. Laminated foil packets help ensure dry storage. Paper packets are best kept in tightly closed jars or other closed containers and maintained at around 40°F in low humidity. The average refrigerator provides ideal conditions for seed storage. Do not freeze seeds.

Saving Seeds from Your Garden Crops

Some gardeners save seeds from their own gardens. These seeds are, however, the result of random open pollination by insects or other natural agents (birds, wind) and may not produce plants identical to the parents. This is particularly true of seeds saved from hybrid cultivars of crops; seeds saved from open-pollinated crop cultivars may produce plants much like the parents. Purchased hybrid cultivars are guaranteed to have the desirable traits of the selected parent plants from which they were bred.

If you choose to save seeds, clean and dry them, then place them in a container that will keep them dry and store it in a cool location. Seeds collected in summer or early fall can be dried outdoors by spreading them thinly on a screen off the ground in shade for about a week. Seeds collected in cooler and wetter periods can be dried indoors where the temperature is above 70°F (preferably in the 80°s).

Seed Germination

Most seed companies take great care in handling seeds properly. Usually, about 80% or more of the seed sown will germinate if optimal conditions for the species are provided. From the seed that germinate, expect about 75% to produce vigorous, sturdy seedlings. Seed germination begins when environmental conditions are satisfactory and when certain internal requirements have been met. A seed must have a mature embryo, contain an endosperm large enough to nurture the embryo, and have sufficient hormones, such as gibberellins and auxins, to initiate the germination process.

The percentage of seed that germinate may be tested at home using a rolled-towel test. Lay moistened paper toweling on a flat surface and place rows of seed on it, starting along one side. As rows are completed, loosely roll up the toweling with the seed inside. Place the rolled tow-

eling and seed under optimal temperature, moisture, and light conditions to induce germination. Check the roll every few days for up to 10 days. Then, count the germinated seed and calculate the germination percentage. For small amounts, test a minimum of 20 seed. If a large amount is available, test 100 seed.

Environmental Factors Affecting Germination

Four environmental factors affect seed germination: water, oxygen, light, and temperature. Optimal levels of light and temperature vary among species, but all seeds require continuous water and oxygen for germination to occur.

Water

Germination begins with the seed absorbing, or imbibing, water. The amount of available water in the germination medium greatly affects water uptake. An adequate, continuous supply of water is needed to ensure germination. Once the germination process has begun, a dry period will cause an embryo to die.

Oxygen

Respiration takes place in all viable seeds. The respiration rate of seeds is low, but some oxygen is required. Because the respiration rate increases during germination, the medium in which the seeds are placed should be loose and well aerated. If the oxygen supply during germination is limited or reduced, germination can be severely retarded or inhibited.

Light

Light stimulates germination in some species and inhibits it in others. In some species, light may have little or no effect. Examples of plants that require light to assist seed germination are ageratum, begonia, browallia, impatiens, lettuce, and petunia. Conversely, the seeds of calendula, centaurea, pansy, annual phlox, verbena, and vinca germinate best in the dark. Other plants' light requirements are not specific at all. Seed catalogs and seed packets often list germination or cultural tips for individual species. Table 5.1 gives light requirements for germination. When sowing seed that require light, leave them on the soil surface. If they are covered at all, cover them lightly with fine peat moss or fine vermiculite. If applied very thinly, these two materials permit some light to reach the seed. Fluorescent lights that are suspended 6 to 12 inches above the seed and operated for 16 hours per day can provide supplemental light in low-light situations (e.g., indoors).

Temperature

Favorable temperatures in the germination medium are also important and affect not only the germination percentage but also the rate of germination (table 5.2). Some seeds germinate over a wide range of temperatures, whereas others require a narrow range. Many seeds have minimum, maximum, and optimal temperatures at which they germinate. For example, tomato seed has a minimum germination temperature of 50°F, a maximum temperature of 95°F, and an optimal temperature of about 80°F. When germination temperatures are listed, they are usually the optimal temperatures, unless otherwise specified. Generally, 65° to 75°F is best for most plants, which means that germination flats may have to be placed in special warming chambers or on radiators, heating cables, or heating mats to maintain optimal temperature. It is extremely important to maintain proper temperature to achieve maximum germination percentages (see table 5.2). Seeds that do not germinate quickly tend to be more prone to disease problems.

Breaking Dormancy

For germination to occur, seeds must be physically and physiologically ready to break dormancy. One of the functions of dormancy is to prevent a seed from germinating before it is surrounded by a favorable environment. Even when the environment is ideal, dormancy is difficult to break in seeds of some trees and shrubs. Various special treatments may be

Table 5.1.

TEMPERATURE AND LIGHTING REQUIREMENTS FOR SEED GERMINATION OF SELECTED ANNUAL FLOWERING PLANTS

Scientific name	Common name	Optimal soil temp. (°F)	Light required*	Days to germinate†
Ageratum spp.	golden ageratum	70	D	5
Ageratum haustonianum (A. mexicanum)	regular ageratum cultivars	70	L	5
Alcea rosea	hollyhock (annual)	60	DL	10
Antirrhinum majus	snapdragon	65	L	10
Begonia semperflorens	begonia (fibrous rooted)	70	L	15
Browallia spp.	amethyst flower, browallia	70	L	15
Calendula officinalis	calendula, pot marigold	70	D	10
Callistephus chinensis	annual aster, China aster	70	DL	8
Catharanthus roseus (Vinca roseus)	periwinkle	70	D	15
Celosia argenta	cockscomb, celosia	70	DL	10
Centaurea cyanus	cornflower, bachelor's button	65	D	10
Centaurea gymnocarpa	dusty miller	65	D	10
Coleus blumei (Coleus hybridus)	coleus	65	L	10
Cosmos bipinnatus	cosmos	70	DL	5
Dahlia pinnata	dahlia (from seed)	70	DL	5
Dianthus chinensis, Dianthus spp.	annual carnation, annual pinks, dianthus, sweet william	70	DL	5–20
Gaillardia pulchella	gaillardia (annual)	70	DL	20
Impatiens walleriana	impatiens	70	L	15
Lathyrus odoratus	sweet pea	55	D	15
Lobelia erinus	lobelia	70	DL	20
Lobularia maritima	sweet alyssum, alyssum	70	L	5
Nicotiana alata (affinis)	nicotiana, flowering tobacco	70	L	20
Nierembergia caerulea	dwarf cupflower, nierembergia	70	DL	15
Petunia hybrida	petunia	70	L	10
Phlox drummondii	annual phlox	65	D	10
Portulaca grandiflora	moss rose, portulaca	70	D	20
Rudbeckia hirta	rudbeckia, gloriosa daisy, black-eyed Susan, coneflower	70	DL	10
Salvia splendens	scarlet sage	70	L	15
Tagetes spp.	marigold (dwarf types and tall types)	70	DL	5
Valeriana officinalis	heliotrope	70	DL	25
Verbena hybrida (V. hortensis)	garden verbena	65	D	20
Viola tricolor, Viola hybrids	pansy, Johnny-jump-up	65	D	10
Zinnia elegans	zinnia	70	DL	5

Source: Adapted by the Ohio State University Cooperative Extension Service from USDA research results released by H. M. Cathey.
Notes:
*D = seed germinate best in darkness; DL = no light requirement; L = seed germinate best in light.
†Usual number of days required for uniform germination at optimal temperature.

required for the seed to break dormancy and stimulate germination.

Seed scarification

Seed scarification involves breaking, scratching, or softening the seed coat so that water can enter and begin the germination process. There are several methods of scarifying seeds. In acid scarification, seed are put in a dry glass container and covered with concentrated sulfuric acid at about twice the volume of seed. (This technique is not recommended for amateur horticulturists because concentrated sulfuric acid is extremely dangerous.) The seed are gently stirred and allowed to soak from 10 minutes to several hours, depending on the hardness of the seed coat. When the seed coat has become thin, the seed can be removed, washed under cold water for 10 minutes, then planted. A second method is mechanical scarification. Seed are filed with a metal file, nicked with a knife, rubbed with sandpaper, or cracked with a hammer to weaken the seed coat. In hot-water scarification, seed are placed in hot water (170° to 212°F), where they soak for 12 to 24 hours as the water cools. The seed are then planted. A fourth method is warm, moist scarification, in which seed are stored in nonsterile, warm, damp containers, where the seed coat is broken down by decay over several months.

Seed stratification

Seed of some fall-ripening temperate-zone trees and shrubs do not germinate naturally unless chilled underground as they overwinter. Some examples include tulip tree, golden rain tree, oaks, sweetgum, and pyracantha. Simulating the environmental requirements for moist chilling may be accomplished artificially by a special treatment called seed stratification.

Table 5.2.

SOIL TEMPERATURE CONDITIONS FOR VEGETABLE SEED GERMINATION

Vegetable	Minimum (°F)	Optimal range (°F)	Maximum (°F)
asparagus	50	75–85	95
bean, green	60	75–85	95
bean, lima	60	75–85	85
beet	40	65–85	95
broccoli	40	60–85	95
cabbage	40	60–85	95
carrot	40	65–85	95
cauliflower	40	65–85	95
celery	40	*	*
chard, Swiss	40	65–85	95
corn	50	65–95	105
cucumber	60	65–95	105
eggplant	60	75–85	95
lettuce	32	60–75	85
muskmelon (cantaloupe)	60	75–85	105
okra	60	80–95	105
onion	32	65–85	95
parsley	40	65–85	95
parsnip	32	65–75	85
pea	40	65–75	85
pepper	60	65–75	95
pumpkin	60	85–95	105
radish	40	65–85	95
spinach	32	65–75	75
squash	60	70–95	100
tomato	50	65–85	95
turnip	40	60–95	105
watermelon	60	75–95	105

Source: Adapted from Lorenz and Maynard 1997.

Note: *Celery requires diffuse light and a night temperature from 10° to 15°F lower than the day temperature for good germination. Optimal conditions are 85°F day and 70°F night with diffuse light and high moisture.

To stratify seeds, put sand or vermiculite in an appropriate container such as a clay pot and fill to about 1 inch from the top. Place the seed on top of the medium and cover with ½ inch of sand or vermiculite. Wet the medium thoroughly and allow excess water to drain through the hole in the pot. Place the pot containing the moist medium and the seed in a plastic bag and tie the bag using a twist tie or rubber band. Place the bag in a refrigerator where the temperature is kept at 35° to 45°F. Periodically check to ensure that the medium is moist but not saturated. Additional water will probably not be necessary. After 10 to 12 weeks, remove the bag from the refrigerator, take the pot out, and set it in a warm place in the house. Water often enough to keep the medium moist. The seedlings should soon emerge. When the young seedlings have developed their first true leaves, transplant them into individual pots until it is time to set them outside.

Another successful germination procedure for seed of woody plants uses sphagnum moss, fine-textured vermiculite, or sand. Wet the medium thoroughly, then allow the excess water to drain. You may need to squeeze excess water from wet moss by hand. Mix the seed with the moist media and place in a plastic bag. Use a twist tie or rubber band to secure the top and put the bag in a refrigerator kept at 35° to 45°F. Check periodically to ensure that the medium is moist. After 10 to 12 weeks, remove the bag from the refrigerator and plant the seed in pots or flats to germinate and grow. Handle seed carefully: often the small roots and shoots are emerging at the end of the stratification period, and care must be taken not to break them off.

Starting Plants from Seeds

Germinating media

Many materials can be used to start seeds, ranging from vermiculite to mixtures of soilless artificial media to the various amended soil mixes. With experience, you can determine what works best under local conditions. Always keep in mind the ideal characteristics of a germinating medium: fine and uniform in texture, yet well aerated and loose; free of insects, disease organisms, and weed seeds; low in total soluble salts; and able to hold moisture yet also drain well. One mixture that

possesses these characteristics is a combination of one-third sterilized sand, one-third vermiculite or perlite, and one-third peat moss. Do not use garden soil by itself to start seedlings, as it is too heavy, not sterile, does not drain well, and shrinks from the sides of containers if allowed to dry out.

Use sterile media and containers. To sterilize a small quantity of soil mixture in an oven, place slightly moistened soil in a covered, heat-resistant container or pan then place the container in an oven set at about 250°F. Use a candy or meat thermometer to ensure that the mix reaches a temperature of 180°F for at least 30 minutes. Avoid overheating, as this can damage the soil. The process may produce an unpleasant odor. This treatment should kill damping-off fungi and prevent many other plant diseases, eliminate potential insect pests, and kill many weed seeds. Containers and implements should be washed to remove any debris, then rinsed in a solution of 1 part chlorine bleach to 9 parts water. Avoid recontamination of the medium with dirty garden tools.

An artificial soilless mix may also provide the desired qualities of a good germination medium. The basic ingredients of lightweight mix are sphagnum peat moss and vermiculite, both of which are generally free of weed seeds and insects.

Ready-made "peat-lite" mixes or similar products are commercially available. To make them at home, combine 4 quarts of shredded sphagnum peat moss, 4 quarts of fine-grade vermiculite, 1 tablespoon of superphosphate, and 2 tablespoons of ground limestone. Another combination is 50% vermiculite or perlite and 50% milled sphagnum peat moss with fertilizer. Mix thoroughly. Because these mixes have little fertility, seedlings must be watered with a diluted fertilizer solution soon after they emerge.

Containers for sowing seeds

Wooden or plastic flats and trays can be purchased or made from scrap lumber. A convenient size is about 12 to 18 inches long and 12 inches wide with a depth of about 2 inches. Leave cracks of about ⅛ inch between the boards in the bottom or drill a series of holes to ensure drainage. Clay or plastic flowerpots can be used. As long as drainage is adequate, recycled household items—such as cottage cheese containers, the bottoms of milk cartons or bleach containers, and pie pans—can be used for starting seed. Containers should be washed thoroughly, then soaked and rinsed in a solution of 1 part chlorine bleach to 9 parts water. This procedure prevents most seedling diseases from occurring.

Numerous types of pots and strips made of compressed peat can also be used to start seeds. Plant bands and plastic cell packs are available as well. Each cell or minipot holds a single plant, which reduces the risk of root injury when transplanting. Peat pellets, peat- or fiber-based blocks, and expanded plastic foam cubes can also be used for seeding. Here, the growing medium itself forms the container unit. When soaked in water, compressed peat pellets expand to form compact individual pots. They make good use of space and maintain their integrity better than peat pots. If you wish to avoid transplanting seedlings, set compressed peat pellets directly out in the garden and sow seeds directly in them. Cell packs, which are strips of connected individual pots, are also available in plastic and are frequently used by commercial bedding-plant growers because they withstand frequent handling. If using recycled cell packs, wash them in a 1-to-9 bleach-to-water solution to sterilize.

Seeding procedures

Time the sowing of seeds for transplants so that plants may safely be moved outdoors after germination. The sowing period may range from 4 to 18 weeks before transplanting, depending on the speed of germination, the rate of growth, and the cultural conditions provided. A common mistake is to sow seeds too early,

then attempt to hold the seedlings back under poor light or improper temperature ranges, which usually results in tall, weak, and spindly plants that do not perform well in the garden.

After selecting a container, fill it to ¾ inch from the top with the moistened medium you have chosen. For very small seeds, at least the top ¼ inch should be a fine, screened mix or a layer of vermiculite. Firm the medium at the corners and edges using your fingers or a block of wood to provide a uniform, flat surface. For medium and large seeds, make furrows about 1 to 2 inches apart and ⅛ to ¼ inch deep across the surface of the container using a narrow board or pot label. Sowing in rows allows good light and air movement and helps prevent the spread of damping-off fungus should it appear. Seedlings in rows are easier to label and handle at transplanting time than are those from seeds sown in a broadcast manner. Sow the seed thinly and uniformly in the rows by gently tapping the seed packet as you move it along the row. If the seed require darkness for germination, use a flour sifter to cover them with an even layer of dry vermiculite.

A suitable planting depth is usually about two to four times the diameter of the seed. Follow printed recommendations on the package. Do not plant seeds too deep. Extremely fine seeds, such as petunia, begonia, and snapdragon seeds, should not be covered but lightly pressed into the medium or watered in with a fine mist spray. If these seeds are broadcast, strive for a uniform stand by sowing half the seed in one direction, then sowing the other way with the remainder.

Large seeds are frequently sown into a small container or cell pack, which eliminates the need for early transplanting. Usually, two or three seed are sown per unit and later thinned to allow the strongest seedling to grow. Some seeds, such as peach or almond, are inside a hardened pit. Remove the seed from the pit prior to sowing. Care must be taken when cracking the pits, as any injury to the seed itself can provide entry for disease organisms.

Seed tape

Most garden stores and seed catalogs offer indoor and outdoor seed tapes. Seed tape has precisely spaced seed enclosed in an organic, water-soluble material. When planted, the tape dissolves and the seed germinate normally. Although they are expensive, seed tapes are especially convenient for tiny, hard-to-handle seeds. Seed tapes allow uniform emergence of seedlings, eliminate overcrowding, and permit sowing in perfectly straight rows. The tapes can be cut at any point for multiple-row plantings, and thinning is rarely necessary.

Pregerminating seeds

Another method of starting seeds is pregermination, which involves sprouting seed before they are planted in pots or in the garden. Lay the seed between the folds of cotton cloth on a layer of vermiculite or similar material in a pan. Keep them moist in a warm place. This technique reduces the time to germination, as the temperature and moisture are easy to control, and it guarantees a high percentage of germination because no seed will be lost to environmental factors. When roots begin to show, place the seed in containers or plant them directly in the garden. While transplanting seedlings, be careful not to break off tender roots or to allow the seedlings to dry out. Continued attention to watering is critical.

When planting seed in a container that will later be set out in the garden, place one pregerminated seed in a 2- to 3-inch container. Plant the seed at only half the recommended depth. Gently press a little soil over the sprouted seed, then add about ¼ inch of milled sphagnum or sand to the soil surface, which will keep the surface uniformly moist but allow shoots to push through easily. Keep the pots in a warm place and care for them just as for any other newly transplanted seedlings.

A convenient way to plant small, deli-

cate, pregerminated seed is to suspend them in a gel. Make a gel by blending cornstarch with boiling water until the mixture is thick enough to suspend the seed. Cool thoroughly before use, then place the gel with seed in a plastic bag with a hole in it. Squeeze the gel through the hole along a premarked garden row. Because the spacing of seed is determined by the number of seed in the gel, add more gel if the spacing is too dense, and add more seed if spacing is too wide. The gel keeps the germinating seed moist until they establish themselves in the garden soil.

Watering during germination

After seed have been sown, moisten the planting mix thoroughly. Use a fine mist spray or place the containers in a pan or tray that has about 1 inch of warm water in the bottom. Avoid splashing or excessive flooding, which might displace the seed. When the planting mix is saturated, set the container aside to drain. The soil should be moist but not wet.

Ideally, seed flats should remain moist enough during germination to need no water. One way to maintain moisture is to slip the whole flat or pot into a clear plastic bag or cover it with clear plastic wrap after the initial watering. The plastic should be at least 1 to 1½ inches above the soil. Keep the container out of direct sunlight to prevent high temperatures from harming the seed. Many home gardeners cover their flats with panes of glass instead of using plastic. Be sure to remove the cover as soon as the first seedlings appear. The surface can be lightly watered if care and good judgment are used.

Lack of uniformity, overwatering, and drying out are problems related to handwatering. Excellent germination and moisture uniformity can be obtained with a low-pressure misting system. Applying mist for 4 seconds every 6 minutes, or 10 seconds every 15 minutes, during the daytime in spring should be satisfactory. Bottom heat is an asset with a mist system. Subirrigation, or watering from below, may work well to keep the flats moist. If the flats or pots sit in water constantly, however, the soil may absorb too much water and the seed may rot because they lack oxygen or contract diseases.

Temperature and light requirements of seedlings

After germination, move the flats to a bright, airy, cooler location that is kept at 55° to 60°F at night and 65° to 70°F during the day. Place them in a window facing south, if possible. If a large, bright window is not available, place the seedlings under fluorescent lights. Use two 40-watt, cool-white fluorescent tubes or special plant growth lamps. Position the plants 6 inches below the tubes and keep the lights on about 16 hours each day. As the seedlings grow, raise the lights accordingly to prevent soft, leggy growth and to minimize incidence of disease. Some crops may germinate or grow best at a different constant temperature than other crops and must be handled separately. Keep the soil evenly moist and do not allow seedlings to wilt. Regular fertilization with half-strength soluble plant fertilizer solution is recommended.

Transplanting and Handling

If the plants have not been seeded in individual containers, they must be transplanted to give them proper growing space. One of the most common mistakes is leaving seedlings in the seed flat too long. The ideal time to transplant young seedlings is when they are small and there is little danger of setback, which is usually when the first true leaves develop above or between the cotyledon leaves (the first leaves produced by the seedling).

Seedling growing mixes and containers can be purchased or prepared similarly to those for seed germination. The medium should contain more plant nutrients than a germination mix, however. Some commercial soilless mixes have fertilizer already added. Use a soluble house plant

fertilizer at the dilution recommended by the manufacturer about every 2 weeks after the seedlings are established. Young seedlings are easily damaged by too much fertilizer, especially if they are under moisture stress.

To transplant, carefully dig and lift small plants with a knife, sharpened pencil, dowel, or wooden plant label. Handle small seedlings by their leaves, not their delicate stems. Gently ease them apart into small groups, so that it is easier to separate individual plants. Tear roots as little as possible in the process. In the medium into which the seedling will be planted, make a hole the same depth at which the seedling was growing in the seed flat. Small plants or slow-growing plants should be placed 1 inch apart, and rapid-growing, large seedlings should be placed about 2 inches apart. After planting, firm the soil and water the transplants gently. Keep newly transplanted seedlings in the shade for a few days or place them under fluorescent lights. Keep them away from sun and direct heat sources. Continue watering and fertilizing using the same procedures as for the seed flats.

Most plants transplant well and can be started indoors. The few plants that are difficult to transplant (such as zinnias, melons, squash, carrots, and potatoes) are generally seeded directly outdoors or sown directly into individual containers indoors.

A wide variety of containers are available for transplanting seedlings. Containers should be economical and durable and make good use of space. The type of container to use depends on the plant and on individual growing conditions. Cell packs, which provide space for several plants, are generally made of plastic, pressed paper, or fiber. Standard pots may be used, but they waste a great deal of space and may not dry out rapidly enough for the seedling to have sufficient oxygen for proper development. Pots made of pressed peat can be purchased in varying sizes. Individual pots or strips of connected pots fit closely together, are inexpensive, and can be planted directly in the garden. When setting out plants grown in peat pots, take care to cover the pot completely. If the top edge of the peat pot extends above the soil level, it may act as a wick and draw water away from the soil in the pot. To avoid this problem, tear off the top lip of the pot and plant the pot so that the lip is flush with the soil level.

Hardening Plants

Hardening is the process of slowing plant growth to withstand changes in environmental conditions that occur when transplants are transferred from a greenhouse or home to the garden. A severe check in growth may occur if plants produced in a controlled environment are planted outdoors without a transition, or hardening, period. Hardening is critical with early crops, when adverse climatic conditions can be expected.

Hardening can be accomplished by gradually lowering temperatures and relative humidity and reducing water, causing an accumulation of carbohydrates and a thickening of cell walls. A change from a soft, succulent type of growth to a firmer, harder type of growth is desired. The hardening process should be started at least 2 weeks before planting in the garden. If possible, plants should be moved to a temperature of 45° to 50°F indoors or outdoors in a shady location. A cold frame is excellent for this purpose. When put outdoors, plants should be shaded, then gradually moved into sunlight, increasing the length of exposure each day. Reduce the frequency of watering to slow growth, but do not allow plants to wilt. Tender seedlings should not be placed outdoors on windy days or when temperatures are below 45°F. Even cold-hardy plants will be hurt if exposed to very cold or freezing temperatures before they are hardened. After proper hardening, however, they can be planted outdoors and light frosts will not damage them.

Propagation of Ferns by Spores

Some gardeners desire to raise ferns from spores, even though ferns are more easily propagated by asexual methods. Reproduction via spores, which are produced inside the brownish dots (spore cases) on the underside of fronds, involves sexual propagation but no seed, because ferns do not produce seed. To propagate small quantities of ferns, sterilize a brick by baking it at 250°F for 30 minutes. Place the sterilized brick in a pan and add water to cover the brick. When the brick is wet throughout, squeeze a thin layer of equal amounts of moist soil and peat onto the top of the brick. Pack a second layer about 1 inch thick on top of the first. Sprinkle spores on top. Cover the brick with plastic (not touching the spores), and put it in a warm place in indirect light. It may take up to a month or more for the spores to germinate. Keep the brick moist at all times. A prothallus (one generation of the fern) will develop first from each spore, forming a light green mat. Mist lightly once a week to maintain a high level of surface moisture; the sperm must be able to swim to the archegonia (female parts). After about 3 weeks, fertilization should have occurred. Pull the mat apart with tweezers into ¼-inch squares and space them ½ inch apart in a flat containing a 2-inch layer of sand, ¼ inch of charcoal, and about 2 inches of soil and peat mix. Cover with plastic and keep moist. When fern fronds appear and become crowded, transplant to small pots. Gradually reduce the humidity until they can survive in the open. Light exposure may be increased at this time.

Asexual Propagation

Asexual propagation is the best way to produce cultivars that closely resemble the parent. Clones are groups of plants identical to one parent; therefore, they can only be propagated asexually. The O'Henry peach and the Double Delight rose are two examples of clones that have been asexually propagated for many years. The principal methods of asexual propagation are cuttings, layering, division, budding, and grafting. Cuttings involve rooting a severed vegetative piece of the parent plant; layering involves rooting a part of the parent then severing it; division involves separating a multicrowned plant into separate plants; and budding and grafting join two plant parts from different cultivars or species.

Cuttings

A cutting is a vegetative plant part that is severed from the parent plant and induced to regenerate itself, forming a new plant. Many woody and herbaceous plants are propagated by cuttings from stems, leaves, roots, or specialized vegetative structures. Cuttings should be made from vigorous plants that are free of diseases and insect pests and have known identities, including varietal names. These identities should be distinctly maintained throughout the life of the plant. Cuttings are classified by the plant part from which they were obtained. Stem cuttings are the most widely used and most important type of cutting. Stem cuttings may be taken at different times of the year, depending on stem maturity and carbohydrate storage in the stem. Leaf and root cuttings are used less frequently but may be the primary propagation method for some species.

Take cuttings with a sharp knife or razor blade to reduce injury to the parent plant. Between cuttings, dip the cutting tool in rubbing alcohol or a solution of 1 part bleach to 9 parts water to prevent the transmittal of diseases. Remove flowers and flower buds from stem cuttings so that their energy and stored carbohydrates can be used for root and shoot formation. Cuttings, except those from soft, fleshy stems, may be placed in a rooting hormone to hasten rooting, increase the number of roots, or obtain uniform rooting. To prevent disease contamination

of the entire supply of rooting hormone, put some of it in a separate container for dipping cuttings. If cuttings must be stored in the refrigerator for any time prior to putting them into rooting medium, avoid storing them with fruits that produce ethylene such as apple or banana. The ethylene may damage the buds and limit root or shoot development.

Insert cuttings into a rooting medium, such as a mixture of coarse sand, vermiculite, soil, and water or a mixture of peat, vermiculite, and perlite. For optimal rooting in the shortest time, choose a sterile rooting medium that is low in fertility, drains well enough to provide oxygen, and retains enough moisture to prevent water stress. Moisten the medium before inserting cuttings, and keep it evenly moist while cuttings are rooting and forming new shoots. Place stem and leaf cuttings in bright, indirect light. Keep root cuttings dark and moist until new shoots appear. Success with cuttings may be variable because of the nitrogen status of the plant, dormancy, and other environmental factors. For example, hardwood cuttings of forsythia taken in January root significantly better than those taken in December or November. Keep notes to document your successes and to allow for repeated success. Small-scale propagation units suitable for the home gardener's cuttings are described later in this chapter.

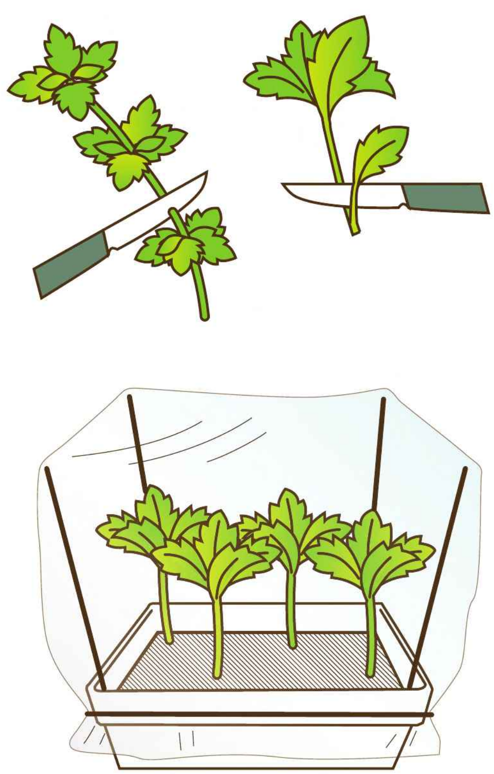


Figure 5.1

Stem tip cuttings for propagating ground covers. Using a sharp knife, clippers, or scissors, take a 4- to 6-inch (10–15 cm) cutting from the tip growth. Remove foliage from the lower 2 inches (5 cm) of stem to reduce water loss. Dip in rooting hormone (optional). Insert cuttings into flats or small pots of moist rooting medium. Keep cuttings enclosed in plastic bags to increase humidity around the rootless plants. Use popsicle sticks, half straws, or other props to hold the plastic off the leaves. Store cuttings in bright but indirect light until roots form. After the cuttings begin to root, gradually open the plastic to let in drier air, and move the flat or pots to brighter light. When the cuttings are well rooted, transplant them to the garden. *Source:* Adapted from Roth 1991.

Softwood stem tip cuttings

Cuttings prepared from soft, succulent new spring growth of deciduous or evergreen species are classified as softwood cuttings. Detach a 2- to 6-inch piece of stem, including the terminal bud. Make the cut just below a node. Remove lower leaves that would touch or be below the rooting medium, and dip the stem in rooting hormone. Insert the cutting into the rooting medium deeply enough to support itself. At least one node must be below the surface. Softwood stem tip cuttings generally work best if you gather cutting material early in the day and use lateral shoots that still have some flexibility but are mature enough so that they would break if bent sharply. Avoid weak, thin, interior stems as well as vigorous, very thick, woody ones, because both will root poorly. The stem tissue that works best can be bruised easily by a nail and will support leaf growth with a gradation in leaf sizes, from small, undeveloped end leaves to mostly older leaves of full size. The timing of softwood cuttings depends on the growth characteristics of the species. Softwood cuttings tend to wilt; keep them moist and cool at all times. Typical softwood stem tip cuttings tend to root in 2 to 5 weeks. A number of ornamentals (e.g., pyracantha, oleander, and veronica) and ground covers (e.g., periwinkle, English ivy, and lamium) can be propagated using this technique, as shown in figure 5.1.

Cuttings from cane-like stems

Cut cane-like stems, such as those from dracaena, dieffenbachia, and croton, into

sections containing one or two nodes. Dust the ends with fungicide or activated charcoal and allow them to dry for several hours. Lay the stem cuttings horizontally, as shown in figure 5.2, with about half of the cutting below the rooting medium surface and the "eye" facing upward. Cane cuttings are usually potted when roots and new shoots appear.

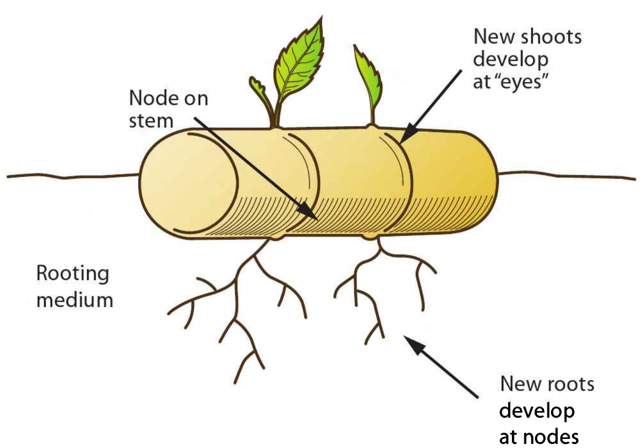
Semihardwood stem cuttings
Broadleaf evergreen species, such as photinia, osmanthus, euonymus, holly, pittosporum, magnolia, and camellia, are propagated best as semihardwood cuttings from mid-July to early September. The plants are ready for cutting when the growth flush is completed, the wood is firm, and leaves have matured. Use cuttings that are from 3 to 6 inches long with the basal half of the leaves removed. Remove any soft growth at the terminus. Dip the stem end into rooting hormone before sticking them into the flat. Rooting the cuttings will take from 4 to 6 weeks. Rooting media such as a 1-to-1 mixture of perlite and peat moss or perlite and vermiculite give good results. Commercially, the cuttings are placed under a misting system during the rooting process. Bottom heating speeds up the process.

Hardwood stem cuttings
From October through late winter, during the dormant season, hardwood cuttings can be taken from deciduous plants that have lost their leaves. Collect wood from last season's growth and cut the stems from 6 to 20 inches long. Treat the basal end with a rooting hormone and bundle the cuttings together. Place the cuttings in a plastic bag or in moist sawdust or peat moss and keep them in a dark, cool location. Placing bottom-heating cables under the bundles may facilitate the rooting process. Once rooting occurs, cuttings can be planted outdoors.

Hardwood cuttings of deciduous species are one of the least expensive, easiest methods of vegetative propagation. The cuttings are easy to prepare, are not perishable, and do not require special equipment during rooting. Wood of moderate size and vigor provides the best stock material for propagation. Central and basal stem cuttings are the best because they contain ample supplies of stored foods to nourish the developing adventitious roots and shoots until the new plants can sustain themselves. Tip portions of the shoot usually have lower amounts of stored food and should not be used for hardwood cuttings. The diameter of the cuttings may range from ¼ inch to 2 inches, depending on the species. Three different types of cuttings can be prepared, as shown in figure 5.3: a straight cut, which does not include any older wood; a heel, which includes a small piece of older wood; and a mallet, which includes a short section of stem from older wood. The straight cut is the most commonly used and usually gives satisfactory results.

Figure 5.2

Cutting from a cane-like stem.



Leaf cuttings
Leaf cuttings (fig. 5.4) are used almost exclusively for a few indoor plants. Leaves of most plants produce a few roots but will not produce a plant; instead, they will just decay. In plants that can regenerate from leaves, such as sansevieria, rex begonia, peperomia, African violet, and jade plant, the leaf blade or the leaf blade plus the petiole can be used to start the new

Figure 5.3

Straight, heel, and mallet hardwood stem cuttings (for tip cuttings, see fig. 5.1). *Source:* Adapted from Bienz 1980, p. 349.

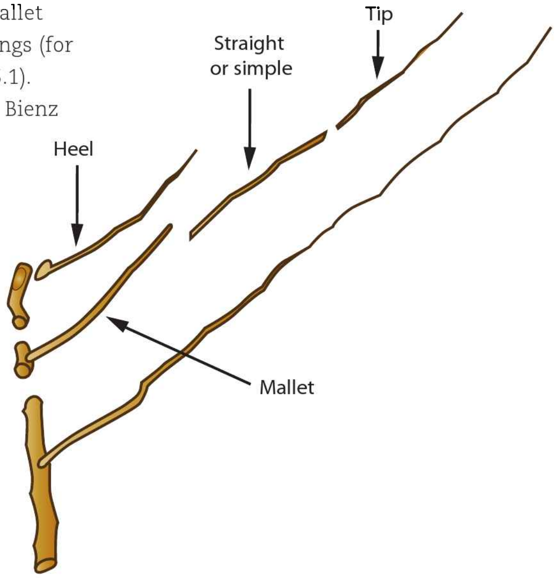
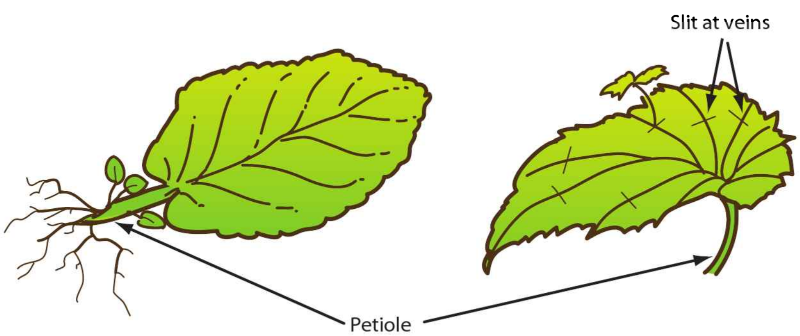


Figure 5.4

Leaf cutting. Adventitious roots and shoots develop at the base of leaf or at the point of slit.



plant. Adventitious roots and an adventitious shoot will form at the base of the leaf. The original leaf does not become a part of the new plant.

African violets can be propagated from leaf cuttings consisting of an entire leaf (the leaf blade plus petiole), the leaf blade only, or a portion of the leaf blade. The new plant(s) form at the base of the petiole or at the midrib of the leaf blade. Insert leaf cuttings vertically into the rooting medium. Leaf cuttings should be rooted under the high-humidity conditions used for softwood stem cuttings. Root-promoting hormones are often helpful. The original leaf may be removed when the new plant has its own roots.

In plants that have leaves with split veins, such as *Begonia rex*, detach a mature leaf from the stock plant. Slit its large veins on the lower leaf surface. Lay the leaf cutting flat, lower side down (where the wounds are), on the rooting medium. Under humid conditions, new plants will form where the veins were cut. If the leaf tends to curl up, hold it in place by covering the margins with the rooting medium. The old leaf blade will disintegrate.

Leaf sections can be used for asexual propagation in some plants, such as snake plant (*Sansevieria* spp.) and fibrous-rooted begonias. Cut fibrous-rooted begonia leaves into wedges with at least one vein. Lay leaves flat on the rooting medium. A new plant will arise at the cut vein. Cut snake plant leaves into sections 2 to 4 inches long. Make the lower cut slanted and the upper cut straight so you can distinguish top from bottom. Insert the basal end of the snake plant leaf section vertically into the rooting medium, covering about three-fourths of its height. Roots will form fairly soon. In time, a new plant will appear at the base of the leaf section, and the original cutting will disintegrate. These and other succulent cuttings will rot if kept too moist.

Root cuttings

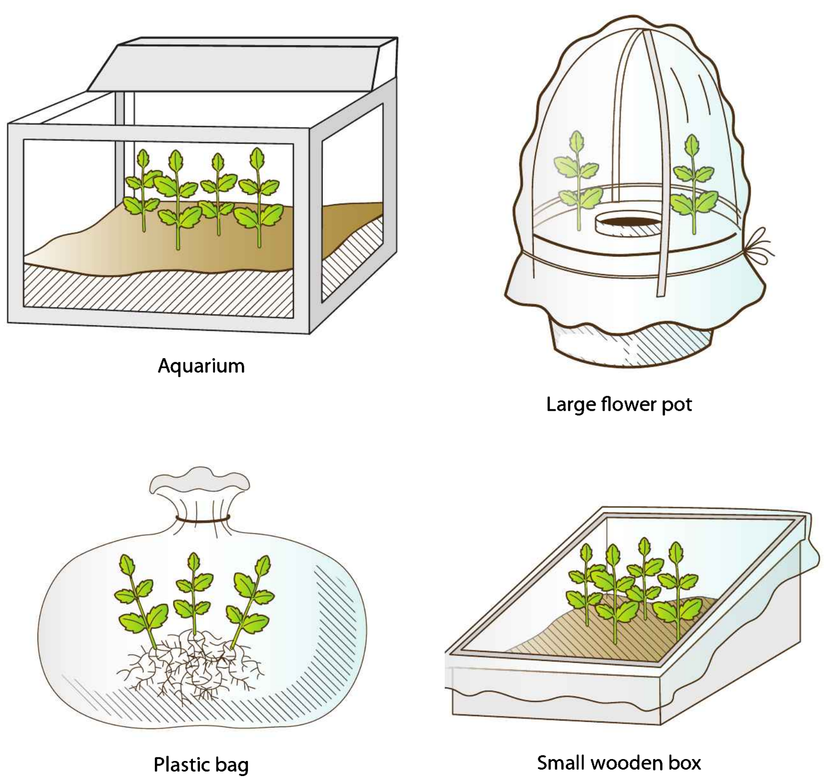
Root cuttings are usually taken from 2- or 3-year-old plants during their dormant season, before new growth starts and while they still have a large carbohydrate supply. Avoid taking root cuttings when the parent plant is actively producing new shoots. Root cuttings of some species produce new adventitious shoots, which then form their own root systems, whereas root cuttings of other plants develop root systems before producing new shoots. When using root cuttings for propagation, maintain the correct polarity, or the cutting will be planted upside down. To propagate

plants with large roots, make a straight top cut of the root section near the crown of the plant. Make a slanted cut 2 to 6 inches below the first cut at the distal (bottom) end. Store the root cutting for about 3 weeks at 40°F in moist sawdust, peat moss, or sand. Remove from storage and insert the root cutting vertically into the rooting medium so that the proximal end (the top end, with the straight cut) is approximately level with the surface of the rooting medium. When root cuttings are used to propagate certain plants with variegated foliage, such as aralias and pelargoniums, the new plants will lose the variegated form. Plants that can be propagated by root cuttings include Japanese flowering quince, phlox, lilac, kiwi, and koelreuteria.

To propagate plants with small, delicate roots, cut 1- to 2-inch sections of the roots and insert the cuttings horizontally into flats about ½ inch below the surface of a fine sand–screened moss medium. After watering the cuttings, place a polyethylene cover or pane of glass over the flat to prevent the cuttings from drying. Set the flats in the shade. This method is usually done indoors or in a hotbed.

Figure 5.5

Small-scale units for propagation of cuttings at home. *Source:* Adapted from Furuta 1976, p. 1.



Small-scale units for propagating cuttings

Small-scale units for propagating cuttings may be made from inexpensive materials commonly found around the home. The units described below are easy to use and care for, do not require constant attention, and can be located in the kitchen, on a porch, or outdoors in a shady location.

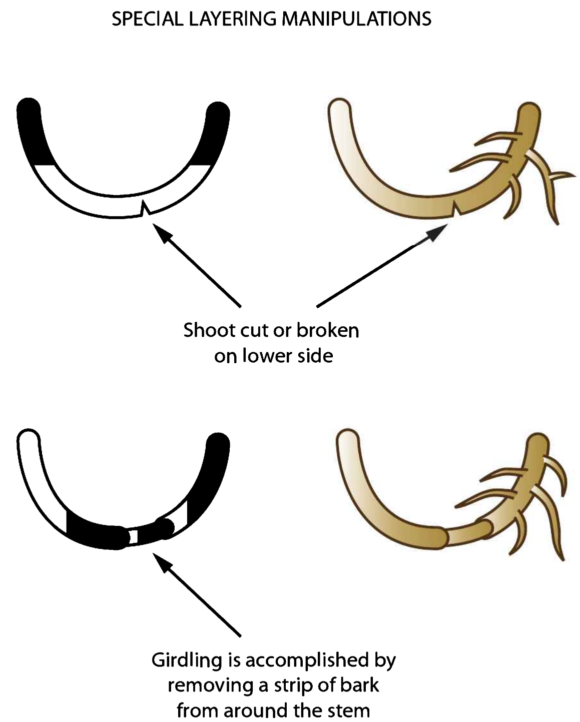
An aquarium (fig. 5.5) can make an ideal unit for home propagation of cuttings. Put a layer of pea gravel in the aquarium, followed by 3 to 4 inches of rooting medium (an alternative is to place small pots or plastic trays containing medium on the pea gravel). Moisten the medium, insert the cuttings, and cover the aquarium with glass or plastic. The cover maintains high humidity, prevents the cuttings from wilting, and hastens rooting.

Large plastic pots, 6 to 8 inches in diameter, can also be converted into propagation units (see fig. 5.5). Seal the drainage hole with putty and fill the pot with rooting medium. Put a 2-inch clay pot in the center of each large pot. Plug up the drainage hole of the small pot and add water. The water will pass slowly through the porous sides of the clay pot into the rooting medium, keeping it uniformly moist. At the same time, evaporation from the surface will maintain a suitable relative humidity inside the propagation unit. If all of the water is used up before rooting occurs, fill the pot again. Place a plastic bag over the cuttings and tie the open end against the pot. Use stakes or wire hoops to keep the plastic from collapsing on the cuttings.

For easy-to-root plants, such as coleus and chrysanthemums, plastic bags alone can be used to root cuttings. Tie a ball of moist sphagnum moss around the base of the cuttings, put them in the plastic bag, and close the opening.

Figure 5.6

Special layering manipulations used to stimulate rooting. *Source:* Adapted from Hartmann and Kester 1990, p. 410.



Small wooden boxes may be converted into propagation units for cuttings. The box should be approximately 12 inches deep, with the top sloped from one side to the other. Seal any cracks or holes. Place a 1-inch layer of pea gravel on the bottom and put 4 inches of rooting medium on top of the pea gravel. Moisten the medium, insert the cuttings, and cover the top with plastic.

The location of the propagation units determines the relative success of rooting the cuttings. Maintain a temperature of 65° to 75°F. The units must remain in heated locations during the winter, but when it is warm enough, they can be kept outdoors in a shady location. Control the intensity of light on the cuttings. Do not place the units in full sunlight because the temperature inside the sealed unit will become too hot and damage the cuttings. Indoors, place the units in a north-facing window or under fluorescent lights that are on for 12 to 16 hours per day. Fluorescent aquarium lights may be used with the aquarium. Although each unit is designed to prevent moisture loss and is therefore expected to retain adequate moisture, moisture levels should be monitored and water added as needed. Misting of the aboveground portion of the cuttings may be required periodically to maintain high humidity.

After the cuttings have rooted, they should be hardened by gradual exposure to normal growing conditions. Gradually remove the plastic coverings over a period of several days. Removing the coverings too suddenly results in wilting, injury, or death of the plants.

Tables 5.3 and 5.4 list methods of propagation for common perennials, house plants, and other garden plants.

Layering

Layering is an asexual propagation method in which adventitious roots are produced on a stem that is still attached to the parent plant. Later, the rooted, or layered, stem is severed to form a new individual plant that grows on its own roots. This method of vegetative propagation promotes a high success rate because it prevents the water stress and carbohydrate shortage that sometimes plague cuttings. Because the stem being layered is still attached, the parent plant continuously supplies water, minerals, and carbohydrates, often making this method more successful than propagation by cuttings. Some plants, such as black raspberries, trailing blackberries, gooseberries, and currants, layer themselves naturally, but plant propagators and home gardeners sometimes assist the process through artificial methods. For the home gardener, layering requires less skill, effort, and equipment than is necessary with cuttings.

Various manipulations of the stem, including girdling, can stimulate adventitious root formation during the layering process (fig. 5.6). Each manipulation of the

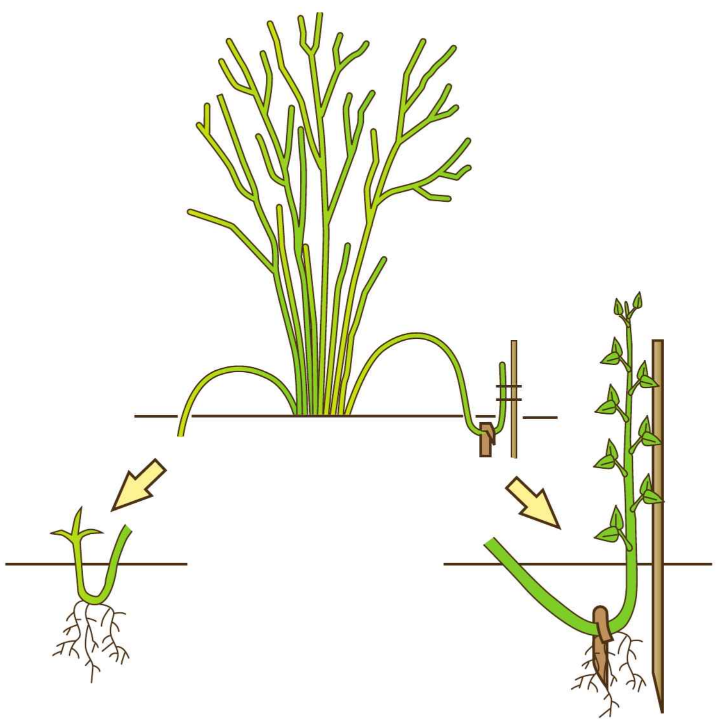
stem interrupts the downward translocation of carbohydrates, growth hormones, and other nutrients from leaves and growing shoot tips, causing these materials to accumulate near the point of stem manipulation. Rooting occurs in this general area even though the stem is still attached to the parent plant. Light is typically withheld from the stem area where root formation is desired. The rooting medium should provide good aeration and a constant supply of moisture. Rooting hormones, applied as a powder, gel, or water soluble, may facilitate rooting during layering.

Tip layering

In tip layering, rooting takes place near the shoot tip of the current year's growth when the shoot tip begins to grow downward into the soil. Later, the stem bends and recurves to grow upward. Roots form at the bend, and the recurved tip becomes a new plant. Remove the tip layer and plant it in the early spring or late fall. This natural method of reproduction is typical of black and purple raspberries and trailing blackberries.

Figure 5.7

Simple layering. Bend shoots over to the ground in early spring or fall. The tip may simply be buried. In some species a second bend is made in the shoot, which is buried and held in place while the tip is staked upright. Rooted layers are removed from the parent plant. *Source:* Adapted from Hartmann and Kester 1990, p. 413.



Simple layering

Simple layering begins with bending the stem to the ground and covering part of it with soil or rooting medium, leaving the last 6 to 12 inches exposed (fig. 5.7). Next, bend the stem tip into a vertical position and stake it in place. The sharp bend often induces rooting, but wounding the lower side of the branch or loosening the bark by twisting the stem may help. Examples of plants for which this method is effective are rhododendron, honeysuckle, wisteria, grape, and dieffenbachia. Simple layering is usually performed on 1-year-old shoots while shoots are still flexible.

Compound (serpentine) layering

Compound layering is essentially the same as simple layering except that the stem is alternately covered and exposed along its length, producing more plants per shoot. Compound layering works well for plants with flexible stems. Wound the lower side of the stem sections to be covered. The exposed portions of the stem should have at least one bud to develop a new shoot. After rooting occurs on the covered portions, cut the branch into sections made up of new shoots and roots. This method is effective for plants such as heartleaf philodendron, pothos, wisteria, and clematis.

Air layering

Air layering is used to propagate some indoor plants with thick stems or to rejuvenate them when they become leggy. Girdle or slit the stem vertically just below a node about 6 to 12 inches from the stem tip. Pry the slit open with a toothpick and remove a strip of bark about ½ to 1 inch wide. Surround the wound with wet, unmilled sphagnum moss and insert some moss into the cut. Wrap clear plastic around the sphagnum moss and tie it in

Table 5.3.

METHODS OF PROPAGATING COMMON PERENNIALS

Scientific name	Common name	Type*	Method of propagation†	Optimal temp. (°F)	Germination	Cold period‡ Temp. (°F)	Cold period‡ Length (days)	Response to light§	Comments
Achillea spp.	yarrow	HP	D, S	68	10				Divide every 2–4 years.
Achimenes spp.	various	b	C, D, S	70					Divide rhizomes after bloom. Use softwood cuttings in spring, leaf cuttings in summer.
Aconitum spp.	monkshood	HP	S			40	42		Poisonous. Do not transplant.
Allium spp.	ornamental onion	B	D, S	68	10				Plant bulblets.
Aloe spp.	aloe	ss	C, D, S	72	25				Plant offshoots, soft cuttings.
Althaea rosea (Alcea rosea)	hollyhock	B	S	68	10–18				
Alyssum spp.	alyssum	HP	C, D, S	77	25	50	5	L	Divide or use softwood cuttings in spring.
Amaryllis spp.	amaryllis	Tb	S						Seed yields flowering bulb in 2–4 years.
Anchusa spp.	bugloss, cape forget-me-not	HA/B	C, D, S	77	25				Seed produces poor-quality plant. Divide or take root cuttings in spring and fall.
Anthemis spp.	chamomile, golden marguerite	HP	D, S	68	21				Divide clumps or start seed in spring.
Aquilegia spp.	columbine	HP	S	77	27	41	25	L	Use commercial seed. Replace every 3 years.
Arabis spp.	rock cress	HP	D, S	68	25				Divide in spring or fall. Softwood cuttings after bloom.
Aster spp.	aster	HP	D, S	68	21				Divide and discard old clump.
Aubrieta	various	HP	C, D, S	55	21				Dividing is difficult. Use softwood cuttings after blooming.
Begonia spp.	begonia	TP	C, D, S	70	15–28			L (fibrous rooted)	Cut rhizomes into sections. Take cuttings in spring and summer. Divide tuberous begonia types.
Bellis perennis	English daisy	HP	D, S	68	14			L	Sow seed in spring or summer. Mulch in fall. Divide every year.
Browallia spp.	amethyst flower, bush violet	TP	C, S	70	15–21			L	Softwood cuttings in fall or spring.
cactus (various genera)	cactus	TP, ss	S	68	slow				
Campanula spp.	bellflower, canterbury bells	HP HB	C, D, S C, D, S	70 77	21 21				Divide clumps in early spring. Sow in late spring or early summer.
Canna spp.	various	TP	D, S	68	28				Divide rhizomes in fall. Soak seed to hasten germination.
Centaurea spp.	dusty miller, cornflower	TP	C, D, S	65–70	10–25			D	Softwood and leaf cuttings in summer. Divide every 2–4 years. Sow seed in spring or summer.
Cerastium tomentosum	snow-in-summer	HP	C, D, S	68	28			L	Softwood cuttings in summer after flowering. Divide in fall.
Cheiranthus spp.	wallflower	hhP	C, S	54	21			L	Take stem cuttings in early summer. Sow seed in early summer.
Chrysanthemum spp.	chrysanthemum, daisy, marguerite	HP	C, D, S	68	28				Take stem cuttings in late spring. Divide clumps every 3–4 years.
Coleus hybridus (blumei)	coleus	TP	C, S	65–70	10–21			L	Take cuttings anytime.
Convallaria majalis	lily of the valley	HP	D						Seedlings take several years to flower. Divide pips in early spring. Mulch in fall.

Key

*A = annual; B = biennial; H = hardy; P = perennial; T = tender; b = bulb; hh = half hardy; ss = succulent.
†C = softwood or leaf cuttings; D = division; L = layered stems; S = seed.
‡Data given for only those species that require cold to germinate.
§L = seed germinate best in light; D = seed germinate best in dark. Data given for only those species that require light or darkness to germinate.

Table 5.3. cont.

METHODS OF PROPAGATING COMMON PERENNIALS

Scientific name	Common name	Type*	Method of propagation†	Optimal temp. (°F)	Germination	Cold period‡		Response to light§	Comments
						Temp. (°F)	Length (days)		
Coreopsis grandiflora	coreopsis	HP	D, S	68	20–25			L	Sow seed in late winter on media surface. Divide established clumps in spring or fall.
Crocus vernus	crocus	HP	D						Seedlings take several years to flower. Separate corms in fall.
Cyclamen spp.	cyclamen	TP	D, S	68	27				Seedlings take several years to flower.
Dahlia spp.	dahlia	TP	D, S	70	5–21				Propagate cultivars asexually. Store clumps over winter at 50°F.
Delphinium spp.	delphinium	HP	C, D, S	54	28				Divide in spring or fall. Sow seed in spring. Softwood cuttings in spring.
Dianthus spp.	carnation, garden pinks	HP	C, S	70	5–20				Softwood cuttings in early summer. Sow seed in early spring/summer. Do not mulch.
Dicentra spp.	bleeding heart	HP	C, D, S			41	42		Softwood cuttings in spring after flowering. Divide in spring or fall and every 4 years. Sow seed in fall.
Digitalis spp.	foxglove	P or B	D, S	70	15–20				Sow seed in spring or early fall. Divide perennial species in fall.
Doronicum spp.	leopard's bane	HP	D, S	68	21				Divide in spring or fall and every 3 years. Sow seed in spring.
Echinacea purpurea	purple cornflower	HP	D, S	75	10–20				Divide or separate rootstock in spring, ensuring that each section has a root. Sow seed in spring.
Echinops exaltatus	globe thistle	HP	C, D, S	77	28				Take root cuttings in early spring, softwood cuttings in fall. Divide in spring.
Freesia spp.	freesia	TP	D, S	68					Propagate from small corms developing on old corms. Dig and store in fall. Soak seed 24 hours before planting.
Geum spp.	geum, avens	HP	D, S	77	28				Divide spring or fall.
Helleborus spp.	hellebore, Christmas rose	HP	S			40	42		Do not divide. Best to grow from seed sown in fall.
Heuchera spp.	coral bells, allum root	HP	C, D, S	77	21			L	Take leaf cuttings in fall. Needs fungicidal treatment. Divide in spring or fall. Use commercial seed.
Iberis spp.	candytuft	HA and P	C, D, S	77	14			L	Take softwood cuttings in summer. Divide in fall. Sow seed in spring.
Impatiens spp.	impatiens	hhA or TP	C, S	70	15–28			L	Start cuttings indoors in spring.
Iresine spp.	bloodleaf, achyranthes	TP	C, S						Start cuttings indoors in winter/spring. Dig and store.
Kniphofia uvaria	red-hot poker, torch lily	hhP	D, S	77	28				Divide or sow seed in spring. Best if left undisturbed.
Lantana spp.	lantana	TP	D, S	77	21				Divide in spring.
Lavandula officinalis	lavender	hhP	C, D, S	70	21				Disturb plantings only for propagation. Take softwood cuttings in summer after bloom. Plant seed in winter.
Liatris spp.	gay feather, blazing star	HP	D, S	77	28				Divide in spring. Sow seed in spring.
Linum spp.	flax	P	C, S	54	28				Cuttings from nonflowering stems in summer. Do not divide. Sow seed in spring or summer.
Lobelia spp.	lobelia	TP	S	70	20				Plant seed in early spring. Divide in spring or fall.
Lobularia maritima	sweet alyssum	P	S	70	5–14			L	Sow seed spring through summer.

Table 5.3. cont.

METHODS OF PROPAGATING COMMON PERENNIALS

Scientific name	Common name	Type*	Method of propagation†	Optimal temp. (°F)	Germination	Cold period‡ Temp. (°F)	Cold period‡ Length (days)	Response to light§	Comments
Lunaria annua (L. biennis)	money plant, honesty	B	S	68	21				Sow seed in summer or spring.
Nepeta spp.	catnip, catmint	HP	C, D	68	21				Take softwood cuttings in summer. Divide in spring and discard old clumps.
Nierembergia spp.	cup flower	TP	C, D, S	70	15–21				Take softwood cuttings in summer. Divide in spring, then leave undisturbed.
Oenothera spp.	evening primrose	HP or B	D, S	77	21				Divide in fall.
Papaver spp.	poppy	HP	C, S	54	14				Use root cuttings of dormant plants. Sow most seed in late summer.
Pelargonium spp.	geranium	TP or A	C, S	70–75	7–10			D	Take leafy softwood cuttings with 3 or 4 nodes in summer. Sow seed indoors in late December to have transplants for outdoors in April–May.
Penstemon spp.	various	hhP	C, D, S	77	21				Take stem cuttings in spring. Divide in spring.
Petunia spp.	petunia hybrids	TP	C	70	10–14			L	Softwood cuttings late summer or fall.
Physalis spp.	Chinese lantern, ground cherry	HP or TP	C, D, S	70	28			L	Root cuttings in fall. Divide in spring or fall. Sow seed in spring.
Polemonium spp.	Jacob's ladder	HP	C, D, S	77	28				Use cuttings or division in spring or summer.
Primula spp.	primrose	HP	D, S	68	42			L	Take cuttings in spring. Divide after flowering.
Ranunculus spp.	buttercup, ranunculus	TP	D, S	68	28				Soak tubers in water for 4 hours before planting. Divide in spring or fall. Sow seed in spring.
Rosmarinus officinalis	rosemary	TP	C. L						Take 4- to 6-inch-long stem tip cuttings in early fall. Layer stems in summer through fall. Seed propagation is unreliable.
Sedum spp.	stonecrop	ss	C, D, S	85	varies				Take cuttings in summer. Disturb only to divide.
Senecio spp.	dusty miller, cineraria, various	TP	C, D, S	68	21				Depending on species, take cuttings or divide in spring, sow seed in spring or late summer.
Stokesia laevis	Stokes aster	HP	C, D, S	77	42				Take root cuttings and divide in spring. Sow seed in spring.
Thymus spp.	thyme	HP	C, D	70	14			L	Take softwood cuttings in summer. Divide in spring.
Tropaeolum spp.	nasturtium	TP	C, S	68	14				Use softwood cuttings only.
Verbena spp.	verbena, vervain	TP	C, S	65	20–28			D	Take softwood cuttings in summer.
Veronica spp.	speedwell	HP	C, D, S	70	14				Take softwood cuttings in spring or summer. Divide in spring or fall.
Vinca major, V. minor	periwinkle, myrtle	TP	C, D, S	68	21				Propagate by softwood cuttings or division in summer.
Viola spp.	violet	HP	C, D, S	65–70	10–21			D	Take cuttings from named cultivars. Sow seed in late summer.
Yucca spp.	yucca	TP	C, D	68	slow				Take root cuttings or divide offshoots in spring.

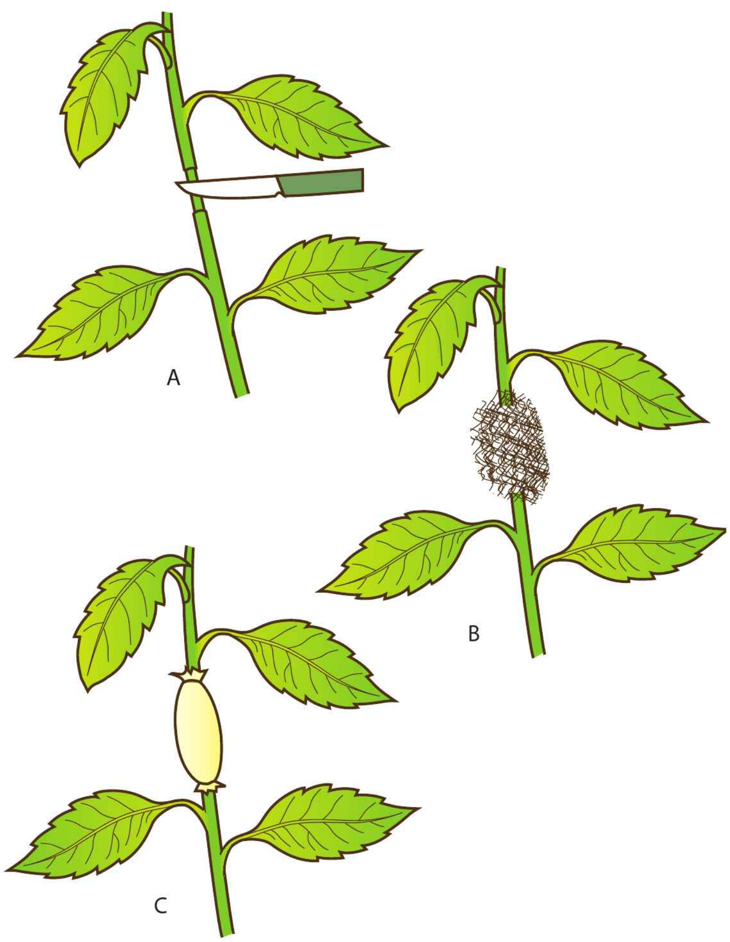
Key

*A = annual; B = biennial; H = hardy; P = perennial; T = tender; b = bulb; hh = half hardy; ss = succulent.
†C = softwood or leaf cuttings; D = division; L = layer stems; S = seed.
‡Data given for only those species that require cold to germinate.
§L = seed germinate best in light; D = seed germinate best in dark. Data given for only those species that require light or darkness to germinate.

place at both ends (fig. 5.8). Polyethylene film is durable, highly permeable to respiratory gases (oxygen and carbon dioxide), and permits little transmission of water vapor. When roots pervade the moss and the stem is not growing too actively, cut the plant off below the root ball. This method is effective for plants such as dumbcane, rubber tree, and *Ficus* spp. Air layering works best using wood from branches about 1 year old that have numerous active leaves that tend to speed up root formation at the site of treatment. It may be necessary to remoisten the sphagnum moss occasionally.

Figure 5.8

Air layering. (A) Completely remove a strip of bark at least ½ inch wide from the internode of the stem. (B) Cover the girdled section with a ball of moist sphagnum moss. (C) Wrap polyethylene film around the sphagnum moss and tie it at each end.



Mound (stool) layering

Cut the plant back to 1 inch above the ground in the dormant season. Mound soil or a coarse organic mulch over the emerging shoots in the spring to enhance their rooting. When roots develop, cut the buried shoots from the base of the parent plant. Plants well adapted to this propagation method produce basal shoots, such as apple, quince, currants, and crape myrtle. This method can be used to produce plants for many years.

Asexual Propagation of Specialized Stems and Roots

Some plants have special vegetative structures whose primary function is food storage and whose secondary function is vegetative (asexual) propagation by natural forms of layering.

Stolons, rhizomes, and runners

Stolons and rhizomes are horizontally growing, often fleshy stems that can root then produce new shoots where they touch the soil or rooting medium. Stolons are horizontal stems that grow above the soil surface, and rhizomes are horizontal stems that grow below it. Ajuga, bermudagrass, and mint can layer naturally (asexually propagate) via stolons. Rhizome structures are found in a number of ornamentals and economically important plants, such as sugarcane, bamboo, banana, ginger, some turfgrasses, bearded iris, and lily of the valley. Such plants are propagated when the rhizomes are cut into sections, with each rhizome piece having one lateral bud, or eye.

A runner is a slender, specialized stem that originates in a leaf axil. The runner grows along the ground, forming new plants at its nodes, or it can grow downward from a hanging basket, producing a new plant at its tip. Plants that produce these structures and naturally layer in this way are propagated by severing the new plants from the parent plants. Plantlets at the tips of runners may be rooted while still attached to the parent or

Table 5.4.

METHODS OF PROPAGATING SELECTED HOUSE PLANTS AND OTHER COMMON GARDEN PLANTS

Scientific name	Common name	Tip or stem cutting	Leaf cutting	Division	Air layer	Other
Abutilon spp.	flowering maple	•				seed
Acacia spp.	wattle	•		•		seed
Acalypha hispida	chenille plant	•				
Acalypha wilkesiana	copper-leaf	•				
Achimenes spp.	various	•		•		seed
Acuba japonica	golddust plant	•		•		
Adiantum cuneatrum	maidenhair fern			•		spores
Aechmea spp.	air plant, bromeliad	•		•		seed
Aeschynanthus javanicus	lipstick plant	•				seed
Agave americana	century plant			•		seed
Aglaonema modestum (*A. commutatum*, *A. simplex*)	Chinese evergreen	•		•	•	
Albizzia julibrissin	silk tree			•		seed
Aloe spp.	unguentine plant			•		
Anthurium andraeanum, *A. scherzerianum*	tall flower			•	•	seed
Aphelandra squarrosa	zebra plant	•	•	•	•	seed
Araucaria exceisa	Norfolk Island pine	•				seed
Asparagus asparagoides	baby smilax	•		•		seed
Asparagus spp.	asparagus fern			•		seed
Aspidistra elatior	cast iron plant			•		
Asplenium spp.	birdsnest fern			•		spores
Azalea spp.	azalea	•				
Begonia spp.	begonia					
fibrous		•				seed
rhizomatous		•		•		seed
rex		•	•	•		seed
tuberous				•		seed
Beloperone guttata	shrimp plant	•				
Bougainvillaea spp.	bougainvillaea	•	•			
Browallia spp.	bush violet	•				seed
cactus (various genera)	cactus	•				seed
Caladium spp.	elephant ears			•		bulbs
Calceolaria herbeohybrida	pocketbook plant	•				seed
Callisia spp.	inch plant	•			•	
Callistemon citrinus	bottlebrush plant	•				
Camellia spp.	camellia	•			•	seed
Campanula isophylla	bellflower	•				seed
Capsicum annuum	Christmas pepper					seed
Carissa grandiflora	Natal plum	•				
Ceropegia woodii	rosary vine	•		•		
Chamaedorea elegans	neanthe bella palm			•		seed
Chlorophytum spp.	spider plant			•		
Chrysanthemum spp.	chrysanthemum	•		•		seed
Cissus antarctica	kangaroo vine	•	•			
Cissus rhomblfolia	grape ivy	•				

Table 5.4. cont.

METHODS OF PROPAGATING SELECTED HOUSE PLANTS AND OTHER COMMON GARDEN PLANTS

Scientific name	Common name	Tip or stem cutting	Leaf cutting	Division	Air layer	Other
Citrus spp.	dwarf citrus cultivars	•			•	seed
Clerodendrum thomsoniae	bleeding heart vine	•		•		seed
Clivia spp.	kaffir lily			•		seed
Codiaeum variegatum	croton	•		•	•	bulbs
Coleus spp.	coleus	•				seed
Columnea microphylla	goldfish plant	•				seed
Cordyline terminalis	Hawaiian ti plant	•		•		
Coreopsis spp.	coreopsis			•		seed
Crassula spp.	jade plant, various	•	•	•		seed
Crossandra infundibuliformis	firecracker flower	•				seed
Cycas revoluta	sago palm			• (or offsets)		seed
Cyclamen spp.	cyclamen			•		seed
Cymbalaria muralis	kenilworth ivy	•				seed
Cyphomandra betacea	tree tomato					seed
Cyrtomium falcatum	fishtail fern			•		spores
Davallia fejeensis	rabbit's foot fern			•		spores
Dianthus carophyllus	carnation	•		•		seed
Dieffenbachia spp.	dumbcane	•		•	•	seed
Dizgotheca elegantissima	false aralia	•		•		seed
Dracaena spp.	various	•		•	•	seed
Dracocephaium virginianum	obedient plant			•		seed
Echeveria spp.	various			•		seed
Epiphyllum spp.	orchid cactus		•			
Episcia spp.	flame violet		•	•		seed
Eucharis grandiflora	Amazon lily					bulbs
Euphorbia pulcherrima	poinsettia	•				seed
Euphorbia splendens	crown of thorns	•				seed
Fatshedera lizei	botanical wonder	•	•		•	seed
Ficus benjamina	weeping fig	•			•	
Ficus elastica	rubber plant	•			•	seed
Ficus lyrata	fiddle leaf fig	•			•	seed
Ficus pumila	creeping fig	•		•	•	seed
Ficus rubiginosa	rusty fig	•			•	seed
Fittonia spp.	mosaic plant	•			•	
Fuchsia spp.	fuchsia	•				seed
Grevillea robusta	Australian silk tree	•				seed
Gynura sarmentosa	velvet plant	•				
Hedera helix	English ivy	•		•		
Helxine soleirolii	baby tears	•		•		
Hemigraphis colorata	red ivy	•			•	
Hibiscus rosa sinensis	Chinese hibiscus	•				seed
Hippeastrum spp.	amaryllis			•		bulbs
Hoya carnosa	wax plant	•	•			
Hypoestes sanguinolenta	polka-dot plant	•				seed

Table 5.4. cont.

METHODS OF PROPAGATING SELECTED HOUSE PLANTS AND OTHER COMMON GARDEN PLANTS

Scientific name	Common name	Tip or stem cutting	Leaf cutting	Division	Air layer	Other
Impatiens sultani	various	•				seed
Iresine spp.	bloodleaf, achyranthes	•	•			
Ixora coccinea	flame-of-the-woods	•				
Jabobinia carnea	various	•				
Jasminum gracile	graceful jasmine	•	•			
Justicia spp.	water willow	•		•		seed
Kalanchoe blossfeldiana, K. tomentosa	kalanchoe, panda plant	•	•			seed
Kleinia articulata	candle plant	•				
Kohleria amabilia	tree gloxinia	•				seed
Lantana camara	yellow sage	•				seed
Lunaria biennis	money plant			•		seed
Maranta leuconeura	prayer plant	•		• (of offsets)		
Mesembryanthemum spp.	fig marigold					seed
Mimosa pudica	sensitive plant					seed
Monstera spp.	various	•			•	seed
Musa nana	dwarf banana			•		seed
Nautilocalyx forgetii	various	•				
Nerium oleander	oleander	•				
Oxalis acetosella	woodsorrel			•		seed
Pandanus veitchii	screw pine			•		seed
Passiflora caerulea	passion flower	•	•			seed
Pentas pentandra	Egyptian star cluster	•				seed
Peperomia spp.	various	•	•	•		seed
Philodendron spp.	philodendron	•	•		•	seed
Phoenix roebelini	pygmy date palm			• (of offsets)		seed
Physalis spp.	lantern plant			•		seed
Pilea cadierei	aluminum plant	•		•		seed
Pilea involucrata	friendship plant	•		•		seed
Pilea microphylla	artillery plant	•		•		seed
Pilea nummulariifolia	creeping charlie	•		•	•	seed
Piper ornatum	ornamental pepper	•				seed
Pittosporum spp.	Australian laurel	•				seed
Platycerium spp.	staghorn fern			•		spores
Plecanthus australis	Swedish ivy	•		•		
Plumbago capensis	leadwort	•		•		seed
Podocarpus spp.	various	•				seed
Polypodium spp.	polypody fern					spores
Polyscias spp.	various	•				
Portulacaria afra	elephant bush	•		•		
Primula spp.	primose			•		seed
Pteris ensioformis	table fern			•		spores
Rheo discolor	Moses-in-the-cradle			•		seed
Rhoicissus capensis	cape grape	•				
Saintpaulia spp.	African violet		•	•		seed

Table 5.4. cont.

METHODS OF PROPAGATING SELECTED HOUSE PLANTS AND OTHER COMMON GARDEN PLANTS

Scientific name	Common name	Tip or stem cutting	Leaf cutting	Division	Air layer	Other
Sanchezia nobilis	sanchezia	•	•			
Sansevieria trifasciata (S. zeylanica)	snake plant, mother-in-law's tongue		•	•		
Saxifraga stolonifera	strawberry begonia		•	•		seed
Schefflera actinophylla	umbrella plant	•			•	seed
Schizanthus spp.	fringe flower					seed
Schlumbergera truncata	Christmas cactus	•	•			
Scindapsus aureus	pothos, devil's ivy	•	•		•	
Sedum morganianum	burrow's tail	•	•			
Senecio cineraria candissimus	dusty miller			•		seed
Senecio cruentus	string of pearls	•				seed
Setcreasea purpurea	purple heart	•				seed
Sinningia speciosa	gloxinia		•			seed/bulbs
Spathiphyllum clevelandii	white anthurium			•		
Stephanotis floribunda	Madagascar jasmine	•				
Strelitzia spp.	bird of paradise			•		seed
Streptocarpus hybridis	cape primrose		•			seed
Streptocarpus saxorum	cape primrose	•		•		seed
Syngonium spp.	arrowhead plant	•	•		•	
Tolmiea menziesii	piggyback plant		•			
Trevesia palmata	snowflake plant	•			•	
Tripogandra spp.	bridal veil	•				
Veltheimia viridifolia	unicorn root					bulbs
Vriesia spp.	king of the bromeliads			•		
Zebrina spp.	wandering Jew	•		•		
Zephyranthes spp.	zephyr lily					bulbs

detached and placed in a rooting medium. Strawberries and spider plants produce runners in this way. In many strawberry cultivars, runner formation is linked to day length and temperature.

Offsets

Plants with rosetted stems often reproduce by forming new shoots at their base or in leaf axils known as offsets or offshoots. Sever the new shoots from the parent plant after they have developed their own root systems. Unrooted offsets of some species may be removed and placed in a rooting medium. Some of these must be cut off, but others may be lifted off the parent stem. This type of natural layering occurs in plants such as date palm, cycads, pineapple, haworthia, bromeliads, and many cacti.

Bulbs

Bulbs are specialized underground stems with a complex anatomy that can produce new bulbs asexually via a natural form of layering, yet they can also reproduce sexually, giving rise to flowers and (sometimes) seed. Also, new bulbs can form asexually beside the originally planted parent bulb. Separate these bulb clumps every 3 to 5 years to encourage large blooms and to increase bulb population. Dig up the clump after the leaves have withered. Gently pull the bulbs apart, remove loose

soil and allow them to dry in a cool, well-ventilated area. Plant at the appropriate time for the climate zone. New small bulbs may not flower for 2 or 3 years, but large ones should bloom the first year. This natural method of layering occurs in tulip, narcissus (daffodil), hyacinth, Cape belladonna, and various lilies.

Corms

A corm is the swollen base of a stem axis enclosed by dry, scale-like leaves. Unlike a bulb, which consists of predominantly leaf scales, a corm is a solid stem structure with distinct nodes and internodes. A large new corm can form on top of an old corm, and tiny cormels can form around the large corm. After the leaves wither, dig up the corms and allow them to dry in indirect light for 2 or 3 weeks. Remove the cormels and gently separate the new corm from the old corm. Dust all new corms with a fungicide and store them in a cool place until planting time. Crocus and gladiolus reproduce naturally via corms.

Tuberous stems and roots

Tuberous stems and roots are thickened underground fleshy structures that contain stored food and may produce new shoots, roots, and plants by asexual propagation. True tubers (tuberous stems) have the same anatomy as a stem. The eyes, which are arranged spirally, are nodes, each having one or more axillary buds. The basal end of the tuber is attached to a stolon on the parent plant. Tubers may be kept whole or cut into sections with one or more buds, or eyes, for planting. Plant tuber pieces 3 to 4 inches deep and allow them to develop new roots and shoots. Plants that reproduce via true tubers include white potatoes, Jerusalem artichoke, and caladium. Tuberous begonias, cyclamen, and gloxinia reproduce via tuberous structures that resemble stems.

Unlike true tubers, tuberous roots have the internal and external structures of roots. They lack nodes and internodes, and buds are present only on the stem end. Their polarity is the reverse of that of the true tuber. Tuberous roots are kept whole and usually placed 2 inches deep in moist, warm sand to promote root and shoot development. Sweet potatoes and dahlia are examples of plants that reproduce via tuberous roots.

Separation and Division

Procedures for vegetatively propagating bulbs and corms are called separation because the bulblets and cormels detach naturally. When the propagator must cut the plant part into sections for propagation, as with rhizomes, tubers, and tuberous roots, the process is called division. Plants with more than one rooted crown may be separated and the crowns planted separately. If the stems are not joined, gently pull the plants apart; if the crowns are united by horizontal stems, such as rhizomes, cut the stems and roots with a sharp knife to minimize injury (see tables 5.3 and 5.4). Plants that have distinct crowns are most easily divided. Some common examples are herbaceous perennials such as Shasta daisy, coreopsis, cast iron plant, primrose, campanula, and daylilies. Multibranched woody plants such as nandina, spiraea, and mahonia can also be divided. If left undisturbed, these shrub plants tend to grow into a thicket. Division is one way to control that tendency.

Crowns of herbaceous perennials are best divided in late summer to fall or in the spring before the emergence of new growth. As a rule of thumb, spring-blooming perennials should be divided in the fall; late-summer or fall-blooming perennials should be divided in early spring.

To divide crowns, dig plants up and cut them into sections with a knife, shovel, or hatchet. The density of the root system will determine which tool to use. To divide woody shrubs, begin by cutting the tops back, then dig up sections of plant and tear them apart, trimming the roots as necessary. The ideal time to divide woody shrubs is during the dormant season, or in winter for evergreen plants.

Grafting and Budding

Grafting and budding are methods of asexual plant propagation that join plant parts so they will grow as one plant. These techniques are used to propagate cultivars that do not reproduce well by cuttings, layering, division, or other asexual methods, or whose own root systems are inadequate. Many species of fruit and nut trees and woody plants are propagated by grafting and budding. New cultivars can be grafted or budded to existing cultivars. The scion, the portion of the cultivar that is to be propagated, is a piece of shoot with dormant buds that will produce the stem and branches. The rootstock, or stock, provides the new plant's root system and sometimes the lower part of the stem. All methods of joining plants are types of grafting, but when the scion is simply a piece of bark (and sometimes wood) containing a single bud, the propagation operation is called budding.

Grafting and budding are preferred to planting seed of a named cultivar of fruit tree because more than 99% of all seedling trees bear fruit inferior to that produced by the parent trees. The fruit of seedlings is the same species, but it is unlike that of the parent tree in flavor, color, date of ripening, and many other characteristics. To obtain a true-to-type fruit tree that is a clone of the parent tree, it is necessary to graft or bud material from the parent onto the desired rootstock. When seedling trees or limbs are larger than 1 inch in diameter, grafting is preferable because it is difficult to bud large-diameter wood.

Certain trees selected for their desirable fruit or ornamental qualities may have root systems that are less desirable; other cultivars of the same species may have desirable root systems that more effectively resist soilborne pests, fungi, and viral pathogens and may better withstand unfavorable soil conditions. When the better scions are grafted onto the better rootstocks, a more vigorous cultivar of higher commercial value can be developed. In citrus species, some rootstocks yield higher-quality, better-sized fruit in some scion cultivars than in others. If desired, the selection of size-controlling rootstocks can cause the composite, grafted tree to become partially dwarfed.

Budding and grafting have additional practical advantages. For example, to extend the fruit-bearing season of a peach tree, a gardener can bud or graft another cultivar of peach onto it. To save space, a pollinating cultivar could be added to a particular fruit tree by grafting. Table 5.5 gives grafting compatibilities of common deciduous fruit trees. Locating bud or graft wood of the desired cultivar can be difficult unless you have neighbors or friends who can help or you are willing to purchase a budded tree from a nursery. In general, nurseries, government agencies, colleges, and universities do not sell or give away small quantities of bud or scion wood of fruit and nut tree cultivars. Also, many cultivars are protected by patent laws and cannot be generally propagated except by the owners of the patent.

As a general rule, the best scion wood is from hardened first- or second-year wood, ⅜ to ¾ inch in diameter, with three or four mature leaf buds (no fruiting buds and no terminal bud). Scions should be stripped of their leaves before grafting. Depending on the technique used, scion wood can be taken from a tree and used promptly, or it can be taken during a dormant period, wrapped in wet paper, sealed, and stored in a refrigerator for later use.

The cambium, a layer of meristematic cells located between the wood (xylem) and bark (phloem) of a stem, is a critical layer of cells in the grafting process. New bark cells and new wood cells will originate in the cambium after successful grafting. Four conditions are required for successful grafting:

1. The cambial layers of the scion and rootstock must come into intimate contact under favorable environmental conditions (both temperature and relative humidity).

2. The scion and rootstock must be compatible for cambial cells to establish the new vascular tissue connection between them.
3. Both the scion and rootstock must be at the proper physiological stage (usually the scion buds are dormant).
4. The graft union must be kept moist until the wound has healed. For the graft union to be successful, new vascular tissue—both xylem (water-conducting tissue) and phloem (sugar-conducting tissue)—must develop to permit the passage of nutrients and water between the stock and scion.

The cells in the cambial area produce callus tissue, which heals the scion (the new top) to the stock.

Whip and tongue grafting

Whip grafting (fig. 5.9) is often used for small material, ¼ to ½ inch in diameter. The scion and rootstock are usually of the same diameter, but the scion may be narrower than the stock. The technique results in a strong graft that heals quickly and provides excellent cambial contact. Make one 2½-inch-long sloping cut at the top of the rootstock and a matching cut at the base of the scion. On the cut surface, slice downward into the stock and up into the scion so the pieces (tongues) will interlock. Fit the tongues together, then tie and wax the union or wrap with plastic tie tape. The best season for whip grafting in California is January through March. Col-

Table 5.5.

GRAFTING COMPATIBILITIES OF COMMON DECIDUOUS FRUIT TREES

	Scion[a]								
Rootstock	Almond	Apple	Apricot	Cherry	Peach and nectarine	Pear	Plum (European and Japanese)[b]	Quince	English walnut
almond	S	I	U	I	P[c]	I	P	I	I
apple	I	S	I	I	I	U	I	U	I
apricot	U	I	S	I	P[d]	I	P[e]	I	I
cherry: Mazzard	I	I	I	S	I	I	I	I	I
cherry: Mahaleb or Stockton Morello	I	I	I	P	I	I	I	I	I
peach	S	I	P	I	S	I	P	I	I
pear	I	U	I	I	I	S	I	U	I
plum: Myrobalan	U	I	P	I	U	I	S	I	I
plum: Marianna 2624	P[f]	U	S	I	U	I	S	I	I
quince	I	U	I	I	I	P[g]	I	S	I
walnut: Northern California black or Paradox	I	I	I	I	I	I	I	I	S

Key:

[a] I = incompatible combination for grafting; the grafts either do not grow or growth is quite weak and short lived. P = partly satisfactory for grafting (most cultivars grow and fruit normally on this rootstock, although some cultivars and some trees do not make satisfactory or permanent graft unions); S = satisfactory for grafting; U = unsatisfactory for grafting, although grafts may grow for a time.

[b] In general, many European and Japanese plums may be grafted on most European plums. Although many Japanese cultivars do well on other Japanese cultivars, European cultivars are not successful on Japanese stocks. Peaches, almonds, and apricots may be grafted on Japanese and European plums with reasonable success, but, as a rule, the grafts fail to grow or do not grow satisfactorily.

[c] Peach trees are short lived and become dwarfed on almond rootstock, but those that are successful make normal tress.

[d] Many individual peach trees fail to grow well on apricot rootstock, but those that are successful make normal trees.

[e] Some Japanese plum cultivars are compatible with some apricot seedlings. In contrast, most European plums are not compatible with apricot rootstocks.

[f] Some almond cultivars, such as Nonpareil, do not make a satisfactory union with Marianna 2624, so an interstock of Havens 2B plum must be used to work such cultivars on this stock. Other cultivars, such as Ne Plus Ultra and Mission, make reasonably satisfactory unions with Marianna 2624.

[g] Some pear cultivars, such as Bartlett, do not make good unions with quince, although other cultivars, such as Old Home and Hardy, do. Therefore, such cultivars as Bartlett are double worked, using one of the compatible cultivars.

Figure 5.9

Whip and tongue grafting. (A) Diagonally cut stock. (B) Cut tongue in stock. (C) Diagonally cut scion with tongue. (D) Fit whip graft together. (E) Wrap whip graft and apply grafting paste. *Source:* Adapted from Beutel and Hartmann 1995, p. 5.

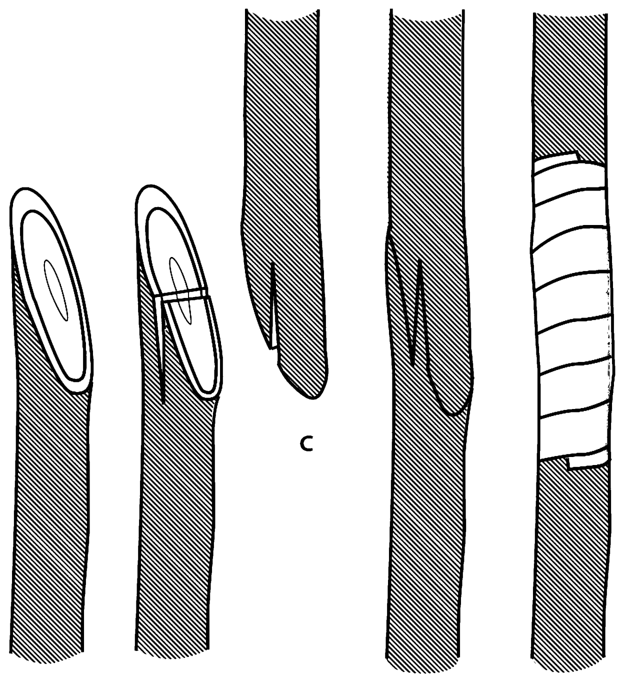
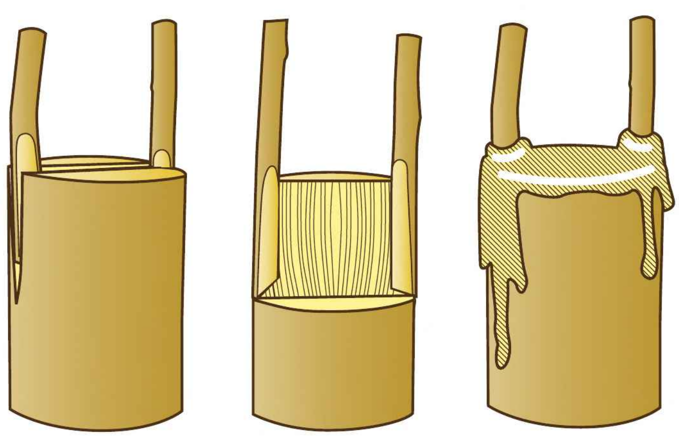


Figure 5.10

Cleft grafting. (A) Scions inserted in place. (B) Part of the stock has been removed to show how the cambium of the scion is brought into contact with the cambium of the stock. You can place the scions at a slight outward slant to make sure the cambiums touch in at least one place. (C) Completed graft covered with wax. *Source:* Adapted from Beutel and Hartmann 1995, p 7.



lect the scion wood (also known as the graft wood) in January and use it immediately, or store it wrapped in moist paper and a plastic bag in the refrigerator for use in February or March. About a month after grafting, the buds on the scion will start to grow. At that time, use a sharp knife to cut through the material tying the graft union. If necessary, use a stake to support the new top.

Cleft grafting

Cleft grafting (fig. 5.10) is often used in topworking established trees to change the cultivar (top growth) of a shoot or a young tree (usually a seedling). It is especially successful if done in late winter or early spring, when the buds of the rootstock are swelling but not actively growing. Collect scion wood that is ⅜ to ⅝ inch in diameter. Cut the limb or small tree trunk to be reworked (the rootstock) perpendicular to its length. Make a 2-inch vertical cut through the center of the previous cut, being careful not to tear the bark, and keep this cut wedged apart. Prepare two scion pieces 3 to 4 inches long. Cut the lower end of each scion piece into a wedge. Insert the scions at the outer edges of the cut in the stock. Tilt the top of the scion slightly outward and the bottom slightly inward so that the cambial layers of the scion and stock touch. Remove the wedge and cover all cut surfaces with grafting wax.

Bark grafting

Unlike most grafting methods, bark grafting (fig. 5.11) can be used on large limbs. The technique works well with persimmon, citrus, avocado, apple, and pear trees and does not require special equipment or extensive training. This technique depends on separating the bark readily from the wood; therefore, it can be done only in the spring after the rootstock has started active growth. Collect scion wood that is ⅜ to ½ inch in diameter in January, when the plant is dormant, and store the wood

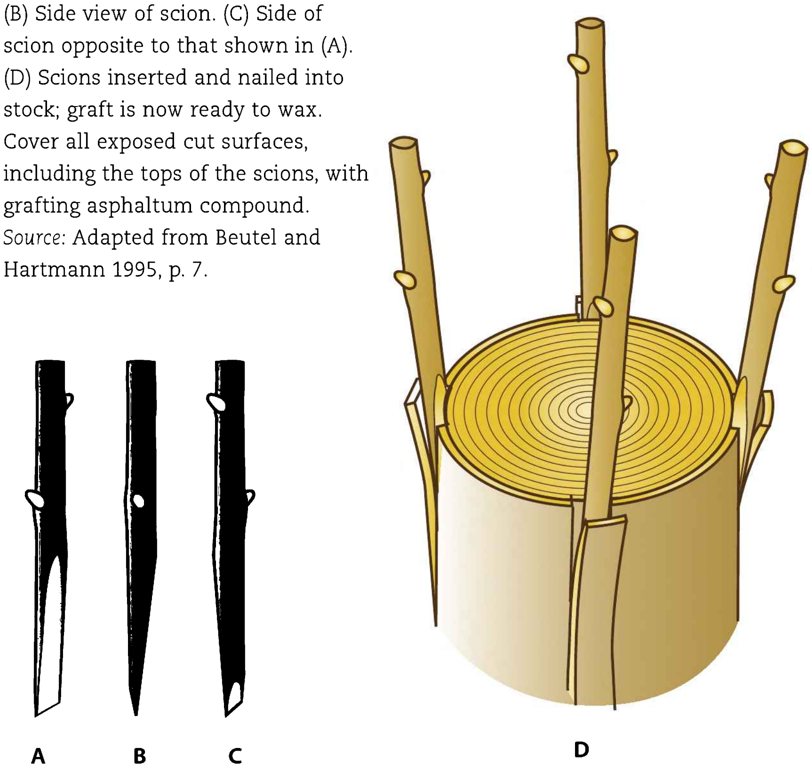
wrapped in moist paper in a plastic bag in the refrigerator. For evergreen species such as citrus, just prior to the grafting operation, collect hardened green-wood scions that are 5 to 6 inches long with 3 to 4 buds. Saw off the limb or trunk of the rootstock at a right angle to itself. In the spring, when the bark is easy to separate from the wood (slipping), make a diagonal cut ½ inch long on one side of the scion, and another diagonal cut 1 to 1½ inches long on the other side. Leave two buds above the longer cut. Cut through the bark of the stock a little wider than the scion and remove the top third of the bark from this cut. Insert the scion with the longer cut against the wood and nail the graft in place with flat-headed wire nails. Cover all wounds with grafting compound.

Graft care

To be successful, maintain proper care for a year or two after grafting. If a binding material such as strong cord or nursery tape is used on the graft, it must be cut shortly after growth starts to prevent it from girdling and subsequently killing the graft. Rubber budding strips are superior to other materials in that they expand with growth and usually do not need to be cut because they deteriorate and break after a short time. Inspect grafts after 2 to 3 weeks to see whether the wax has cracked. Rewax the exposed areas if necessary. After this period, the graft union will probably be strong enough so that more waxing is not necessary. For the first year, select one or two limbs of the old cultivar that were not selected for grafting and maintain them as nurse limbs. The total leaf surface of the old cultivar should be gradually reduced as that of the new cultivar increases. Removing all the limbs of the old cultivar at the time of grafting increases the shock to the tree and may cause excessive suckering. The scions may grow too fast, making them susceptible to wind damage. By the end of 1 or 2 years, the new cultivar will have taken over, and ungrafted nurse branches can be removed or also grafted over.

Figure 5.11

Bark grafting. (A) Side of scion that is placed against the wood of the stock. (B) Side view of scion. (C) Side of scion opposite to that shown in (A). (D) Scions inserted and nailed into stock; graft is now ready to wax. Cover all exposed cut surfaces, including the tops of the scions, with grafting asphaltum compound. *Source:* Adapted from Beutel and Hartmann 1995, p. 7.



Budding

Budding, or bud grafting, involves removing a bud and a small piece of bark from the scion and grafting it onto a rootstock. The nursery industry uses this technique for propagating roses and fruit trees sold to home gardeners and orchardists. Budding takes advantage of the same physiological processes as other forms of grafting, but it is faster and forms a stronger union and uses buds from smaller-diameter wood. It is especially useful when scion material is limited. Commonly used, budding requires that the bark be slipping, a condition in which bark separates easily from wood. Slipping occurs from spring to fall when the plant is growing, cambial cells are dividing actively, and newly formed tissues can be torn as bark lifts from the wood.

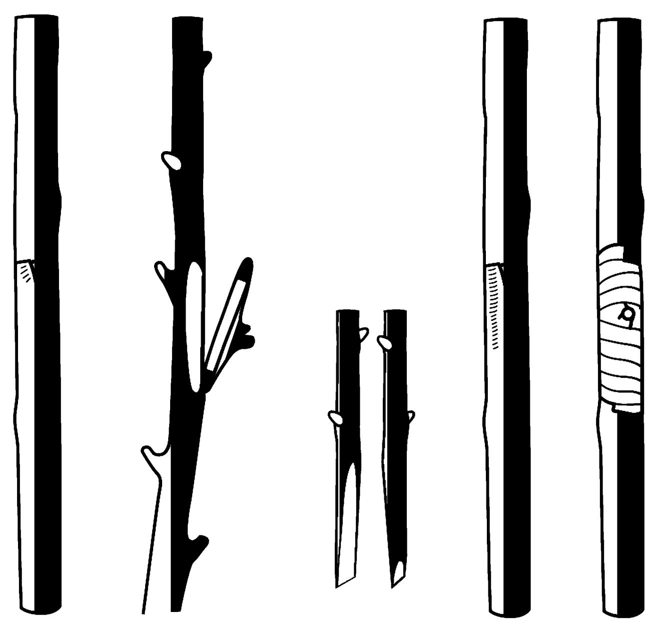
In California, the season for budding is April through August. To bud trees from

June through August, select budwood from the current season's growth that is 2 to 10 months old and can easily be cut. Use wood that is ¼ to ⅜ inches in diameter, and cut off the leaves. Good budwood is firm and has narrow, pointed leaf buds, not flower buds. If you are planning to bud in April, collect wood from dormant trees in January. Wrap the dormant wood in moist (not wet) paper and place it in a plastic bag in a refrigerator set at 32° to 35°F until needed.

For trees budded from April through June, use the techniques described below and cut off the top of the stock just above the bud, forcing the bud to grow. To bud trees in August, however, do not cut off the top of the seedling until the following spring because the bud should remain dormant. In March, cut August-budded trees above the inserted bud to force growth of the bud. About a month after budding an actively growing tree, cut the ties around the bud, beginning on the side opposite the bud, so that they do not girdle the tree. Remove suckers that grow on the rootstock after budding. Use stakes to support the new, growing shoot if necessary. Some plants bud in spring, others in the fall. To force the bud to develop the following spring, cut the stock off 3 to 4 inches above the bud. The new shoot may be tied to the resulting stub to prevent wind damage. After the shoot has made a strong union with the stock, cut the stub off close to the budded area.

Figure 5.12

T-budding. (A) Make a T-shaped cut in the stock. (B) Cut the bud from the stock. (C) Front and side views of cut buds. (D) Bud partly inserted in the stock. (E) Wrapped bud. *Source:* Adapted from Beutel and Hartmann 1995, p. 4.



T-budding

The budding technique most commonly used by nursery staff in propagating roses, deciduous fruit trees, citrus, avocado, and ornamental shrubs is called T-budding because of the T-shaped appearance of the cut in the stock. Its use is limited to actively growing stocks that are ¼ to 1 inch in diameter and have fairly thin bark that separates easily from the wood. Figure 5.12 illustrates steps in making a T-bud.

Patch budding

In patch budding, a rectangular patch of bark is removed completely from the stock and replaced with a patch of bark of the same size containing a bud of the cultivar to be propagated. For thick-barked trees, especially walnut and pecan, the patch bud often outperforms the T-bud or chip bud. Trees should be patch budded while they are actively growing in late summer or early fall so that their bark slips easily. Remove a rectangular piece of bark from the scion. If the rootstock's bark is thicker than that of the scion, pare it down to meet the thinner bark so that when the union is wrapped, the patch will be firmly held in place.

Chip budding

Chip budding can be done when the bark is not slipping. Slice downward into the rootstock at a 45° angle through one-fourth of the wood. Make a second cut upward from the first cut, about 1 inch long. Remove a bud and attending chip of bark and wood

from the scion shaped so that it fits the rootstock wound. Fit the bud chip to the stock and wrap the union.

Plant Tissue Culture for the Home Gardener

Although technical procedures for aseptic (sterile) culture of plant cells, tissues, and organs are as diverse as the plant materials on which they are practiced, a simplified general procedure can be followed in the home. The necessary supplies can be obtained at the local grocery store. The procedures outlined below can be used for plants that are easy to propagate (African violets, coleus, and chrysanthemums) or those that are difficult (orchids, ferns, weeping figs). Although the propagation techniques are simple and straightforward, the media can easily become contaminated by bacteria, and this method may not always work at home.

Media preparation

To prepare 2 pints of growth media for plant tissue culture, mix the following ingredients in a 1-quart home canning jar:

⅛ cup sugar

1 teaspoon all-purpose soluble fertilizer mixture (check the label to make sure it has all of the major and minor elements, especially ammonium nitrate; if the latter is lacking, add ⅓ teaspoon of a 35-0-0 soluble fertilizer)

1 tablet (100 mg) of inositol (myo-inositol), which can be obtained at most health food stores

one-quarter of a pulverized vitamin tablet containing 1 to 2 mg thiamine

4 tablespoons coconut milk (cytokinin source) drained from a fresh coconut (the remainder can be frozen and used later)

60 mg of a commercial powdered rooting compound that has 0.1% active ingredient IBA (indolebutyric acid, a type of auxin)

Add distilled or deionized water to fill the jar. If purified water is not available, substitute water that has been boiled for several minutes. Shake the mixture and make sure all materials have dissolved.

Baby food jars or other heat-resistant glass receptacles with lids can be used as individual culture jars. To support the plant material, add cotton or paper until the jar is half full. Pour medium into each culture bottle so that the support material is just above the solution.

When all bottles contain the medium and have their lids screwed on loosely, they are ready to be sterilized. Place the jars in a pressure cooker and sterilize them under pressure for 30 minutes, or place them in an oven at 320°F for 4 hours. After removing the bottles from the sterilizer, place them in a clean area and allow the medium to cool. If the bottles will not be used for several days, wrap groups of culture bottles in foil before sterilizing, then sterilize the whole package. Then the bottles can be removed and cooled without removing the foil cover. Sterilized water, tweezers, and razor blades, which will be needed later, can be prepared in the same manner.

Plant disinfection and culture

Once the growth medium is sterilized and cooled, plant material can be prepared for culture. Various plant parts can be cultured, but small, actively growing portions usually produce the most vigorous plantlets. For example, ferns are most readily propagated by using only ½ inch of the tip of a rhizome. For other plants, ½ to 1 inch of the shoot tip is sufficient. Remove leaves attached to the tip and discard. Because plants usually harbor bacterial and fungal spores, they must be cleaned (disinfected) before placement on the sterile medium. Otherwise, bacteria and fungi may grow faster than the plantlets and dominate the culture. Place the plant part into a solution of 1 part bleach to 9 parts water for 8 to 10 minutes. Submerge all plant tissue in the bleach solution. After this time, rinse off excess bleach by dropping the plant part into sterile water. Remember, once the plant material has

been in the bleach, it has been disinfected and should be touched only with sterile tweezers.

After rinsing, remove any bleach-damaged tissue with a sterile razor blade. Then remove the cap of a culture bottle containing sterile medium, place the plant part onto the support material in the bottle (making sure that it is not completely submerged in the medium), and recap quickly. These procedures, known as the transferring process (transferring the plants into the culture jars), should be done as quickly as possible in a clean environment. Scrub hands and countertops with soap and water just before beginning to disinfect plant material. Rubbing alcohol or a diluted bleach solution can be used to wipe down the work surface.

After all plants have been cultured, place them in a warm, well-lit (no direct sunlight) environment to encourage growth. If the medium has become contaminated, it will be obvious within 3 to 4 days. Remove and wash contaminated culture bottles as quickly as possible to prevent the spread of disease to uncontaminated cultures.

When plantlets have grown to a sufficient size, transplant them into soil. Handle them as gently as possible because the plants will be leaving the warm, humid environment of the culture jar for the cool, dry soil. After transplanting, water the plants thoroughly and place them in a clear plastic bag for several days. Gradually remove the bag to acclimate the plants to their new environment. Start with 1 hour per day and gradually increase time out of the bag over a 2-week period until the plants are strong enough to dispense with the bag altogether.

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Plant Pathology 6

Deborah Silva, Dennis R. Pittenger, and Demetrios G. Kontaxis

Learning Objectives

Develop a general understanding of basic plant disease concepts and principles. Become acquainted with the terminology professionals use to describe and discuss plant diseases and their control.

Learn the major types of pathogens (parasitic agents) and environmental factors (nonparasitic agents) that cause diseases in plants.

Develop a general understanding of how plant pathogens may or may not cause disease when they interact with the surrounding environment and their hosts.

Learn examples of common plant diseases.

Develop an understanding of how to distinguish disease symptoms from other plant injuries.

Learn the basic strategies for controlling plant diseases.

This chapter is intended to be used in conjunction with University of California Integrated Pest Management manuals and the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden.

Plant Pathology

What Is Plant Pathology?

Plant pathology, or phytopathology, is the science of plant diseases. A plant pathologist is a "plant doctor" who has the knowledge to recognize disease symptoms, diagnose their cause, and recommend strategies to prevent and manage disease outbreaks. Plant pathologists study diseases caused by fungi, bacteria, viruses, viroids, phytoplasmas (formerly known as mycoplasmalike organisms), spiroplasmas, nematodes, parasitic plants, and protozoa, all of which are collectively called plant pathogens. Of course, not all fungi, bacteria, and nematodes are pathogens; most species are either neutral or beneficial to plant growth, but those that cause disease are known as pathogens.

Crop plants under pathogen attack are known as host plants. Host plants may be susceptible to getting a disease, depending on their inherent genetic resistance, overall health, and the surrounding environmental conditions, which include temperature, moisture, sunlight, and soil status. Because environmental conditions must be favorable for disease to occur, plant pathologists must study the interactions among the pathogen, the environment, and specific host plants to evaluate preventive measures, alleviate damage, and develop effective control strategies.

Plant pathologists also study abiotic plant disorders, which are caused by environmental factors such as air pollution, drought, nutrient deficiencies, mineral toxicities, freezing temperatures, pesticide toxicities, lack or excess of light, or improper cultural practices. Plant damage caused by insects or animals is usually not included in the study of plant pathology, although insects can serve as vectors (carriers) that transmit certain pathogens to plants. When insect carriers are an important factor in the development of a particular disease, the combined expertise of plant pathologists and entomologists can contribute to effective control strategies.

Plant pathology is a practical science born of necessity for human survival. Among the earliest written records of plant diseases are those found in the Bible's Old Testament, describing blights and mildews (see 1 Kings 8:37). The Greek philosopher Theophrastus (374–288 BC) recorded his observations and

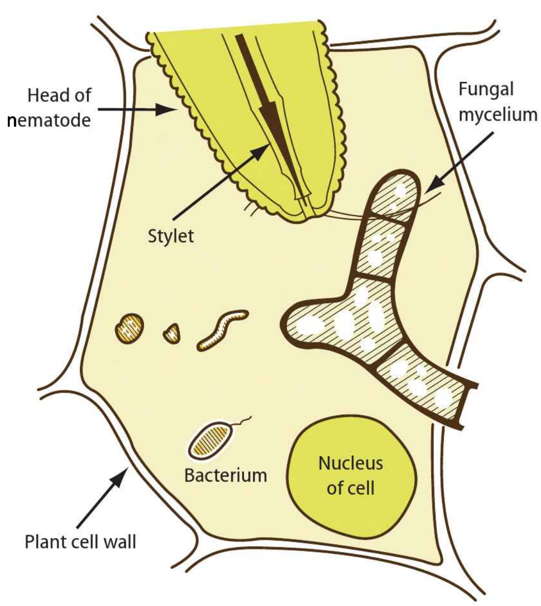


Figure 6.1

Shapes and sizes of certain plant pathogens in relationship to a plant cell. *Source:* After Agrios 2005, p. 7.

speculations about diseases of trees, cereals, and legumes. The Romans revered the rust god, Robigo, whom they appeased to protect grain crops from rust diseases. Every spring, before rusts could take hold, the Romans celebrated Robigalia by sacrificing red dogs and sheep to pacify Robigo and protect the harvest.

For nearly 2,000 years, little progress was made in the science of plant pathology. Not until the compound microscope was invented in the middle of the seventeenth century were significant advances made in understanding the causes of plant disease and in managing them. Many pathogens of economic importance are microscopic and cannot be seen and studied without the aid of a compound microscope. Figure 6.1 is a schematic diagram of the shapes and sizes of several plant pathogens in relationship to the size of a generic plant cell. Some pathogens cannot be visualized without the aid of a phase-contrast or electron microscope. Since the invention of these viewing aids, the roles of fungi, bacteria, viruses, and other microorganisms in the development of plant disease have been studied and elucidated.

Despite significant advances in plant pathology and other biological sciences, huge crop losses are still experienced throughout the world, showing that much is yet to be learned about plant diseases and their control. An estimated $9 billion in crops—about 10 to 12% of the crop before harvest—is lost annually to plant disease in the United States alone. Such preharvest losses from disease in the field must be combined with postharvest losses from pathogens that attack food in storage to arrive at a rough total of the significant effect of plant disease on the food supply. These total annual food losses bring into sharp focus the reality that plant pathology has yet to overcome many microbial pathogens and environmental stresses. When the effects of plant disease are coupled with food losses from insect pests and weeds, an even more striking picture emerges. Preharvest and postharvest losses caused by the three major pests of crops—diseases, insects, and weeds—are estimated to be 40% of the total crop in the United States and 48% worldwide, despite all of the advances in pest control techniques.

In their mildest forms, plant diseases can be a localized, manageable problem confined to one person's garden. Although a disease epidemic is commonly thought of as a widespread, severe outbreak that occurs over a large area within a relatively short time, technically speaking, an epidemic is any increase in the frequency of disease. An epidemic can occur on a very small scale or it can have profound, far-reaching effects. If a disease epidemic involves an important food crop, it can result in famine, which can contribute to the death of millions of people. If a disease epidemic involves an important nonfood crop, it can devastate the economy of an industry. For example, in 1845 and 1846, a microscopic plant-pathogenic fungus, *Phytophthora infestans*, destroyed the potato crop in Ireland and caused a severe disease outbreak known as the late blight of potato epidemic, which, combined with political, economic, and social factors, resulted in the death of nearly a third of Ireland's population and led to the emigration of millions of people to the United States. By 1940, about 35 years after its introduction into New York City, *Endothia parasitica*, the fungus that causes chestnut blight disease, destroyed nearly all American chestnut trees in the eastern United States and devastated the hardwood timber industry. The citrus tristeza virus (CTV) almost destroyed the citrus industry in California in the 1940s because the sour orange rootstock on which the sweet orange scions were grafted at the time was susceptible to the quick-decline strain of the virus. Scientists at the University of California identified the disease, determined how it was transmitted (by grafting and aphids), and conducted research to test for and develop a CTV-

resistant rootstock (Troyer Citrange). Today, Troyer citrange is one of the rootstocks of choice in the California citrus industry because of its resistance to CTV, especially its quick-decline strain. Coffee rust, the most destructive coffee disease, caused by the fungus *Hemileia vastatrix*, destroyed all coffee trees in Southeast Asia in the late 1800s. In Great Britain, coffee rust was an important factor in tea replacing coffee as that nation's refreshment of choice. Coffee rust appeared for the first time in the Western Hemisphere in 1970 and continues to spread steadily into the world's important coffee-producing countries in South America. Today, disease-resistant varieties of coffee trees minimize losses.

Plant pathogens introduced into an area via modern global transportation would be expected to cause more damaging epidemics than local pathogens. Crops previously unexposed to the foreign pathogen would not have been pressured to select for genes resistant to the pathogen and would be more vulnerable to attack by the invader. Recognizing this danger, Congress passed quarantine laws in 1912 to restrict the entry of foreign plants, plant products, soil, and other materials into the United States to protect the nation's agriculture, gardens, and forests. Today, the Animal and Plant Health Inspection Service (APHIS) has quarantine inspectors stationed at entry points into the United States and at certain interstate points to prevent the introduction of foreign plant pathogens into new areas. Other countries also impose quarantines.

Advances in genetic engineering of viruses, bacteria, and fungi and their application to management of crops and landscape plants are expected to usher in a new era of disease control. Plant pathologists are currently studying the genes that enable pathogens to be virulent in order to identify, isolate, modify, inhibit, and neutralize them. Scientists are also studying the genes that enable certain host plants to resist attack by certain pathogens. Plant pathologists are developing techniques to transfer pathogen-inhibition genes and disease-resistance genes to crop plants to protect them from pathogen attack. Diagnostic test kits based on genetic engineering principles are available to detect and diagnose selected diseases caused by particular pathogens, and test kits for others are under development. It is difficult to predict how and when biotechnology techniques will significantly reduce annual crop losses from plant disease, but many plant pathologists are very hopeful that these new technologies will be as important as the compound microscope in advancing the science of plant pathology.

What Is Plant Disease?

Not all plant pathologists agree about the precise definition of plant disease. In the current scientific literature, two points of view predominate. The first view is that only pathogens (fungi, bacteria, viruses, etc.) can cause plant disease, whereas abiotic (nonliving) environmental stresses (smog, drought, nutrient deficiencies, mineral toxicities, etc.) cause abiotic plant disorders or damage, not disease, even though many symptoms they induce on host plants are similar to those caused by pathogens. A more inclusive definition of disease encompasses pathogens and environmental stresses as causes of disease. Plant pathologists subscribing to the second definition view disease as the series of responses of plant cells and tissues to a pathogen or an environmental factor that result in undesirable changes in form, function, or health of plant parts or the whole plant. Disease is a dynamic process resulting from a continuous association of a plant with a pathogen or environmental factor and leads to expression of symptoms. Diseases caused by pathogens are termed infectious diseases and the diseases caused by environmental factors are termed noninfectious diseases under this definition. Because noninfectious diseases do not involve pathogens, they cannot be

transmitted from diseased to healthy plants. Environmental factors can increase the incidence of pathogen-mediated disease by rendering plants more susceptible to pathogen attack, however. Regardless of their positions on this debatable issue, pathologists do concur on the adverse symptoms expressed in host plants.

The discussion in this chapter is based on the more inclusive definition of plant disease. A distinction is made between infectious diseases caused by pathogens and noninfectious diseases caused by environmental stresses. Abiotic disorders and damage are described as symptoms of noninfectious disease in this chapter.

Basic Concepts and Principles of Infectious Plant Disease

How and When Infectious Disease Develops: The Disease Cycle

Infectious diseases are dynamic, biological processes caused by the continuous interaction of a pathogen with a host under environmental conditions that favor disease development. Plant diseases disrupt normal, healthy plant growth. For an infectious disease to develop, a series of events called the disease cycle must occur: inoculation; penetration; establishment of infection (which includes invasion of host plant tissues and growth and reproduction of the pathogen); dissemination of the pathogen; and survival of the pathogen (overwintering or oversummering in the absence of the host).

Inoculation

The first event in the disease cycle is inoculation, which occurs when the pathogen comes into contact with a susceptible host. Pathogens capable of causing infection that come into contact with host plants are known as inoculum. One unit of pathogen inoculum is called a propagule. Wind currents, irrigation or rain water, and insects can carry the inocula of many pathogens to host plants. An inoculum may consist of a single windborne fungus spore, or it may consist of millions of bacteria carried in a droplet of irrigation water. Successful inoculation requires favorable environmental conditions, such as relative humidity and temperatures favorable to the inoculum interacting with a susceptible host. If temperatures are too hot or cold and relative humidity is too low, the inoculum can desiccate and die before infection has a chance to occur.

Penetration

After inoculation, some pathogens can directly penetrate cells: they produce enzymes that soften the cell walls of the host and use mechanical force to pierce through and gain entry into the host under attack. Many fungi, nematodes, and parasitic plants attack their hosts by direct penetration. Other pathogens enter passively through wounds, stomata (the pores on leaves through which plants transpire), or other natural openings. Because fungi, bacteria, and some viruses can enter plants through wounds, prune plants carefully and at the appropriate times of year, when penetration by pathogen inoculum and disease development are not favored.

Infection

Infection is the process by which an inoculum establishes continuous contact with susceptible cells or tissues of the host plant and sets up a parasitic relationship, procuring its food (nutrients) from the host. Penetration may lead to infection or disease, depending on environmental conditions and the host's susceptibility or resistance to the pathogen. When infection occurs, pathogens grow and multiply on or within host plant tissues, invading other tissues of the host's body, reproducing there, and feeding on the host. Many pathogens release enzymes, toxins, and growth regulators inside the host plant, which lead to disorganized, unhealthy growth in susceptible host plants and

increasing populations of the pathogen feeding inside the host. Successful infection may lead to disease symptoms such as wilting, leaf curling, the appearance of discolored, malformed, or dying (necrotic) areas on the host plant; fruit drop; or stunted growth. Other infections are latent, and symptoms do not occur immediately. The interval between inoculation and the appearance of disease symptoms is known as the incubation period, which may last from a few days to years, depending on the particular host-pathogen combination and surrounding environmental conditions.

During the infection stage of the disease cycle, pathogens invade host plant tissues, either intercellularly (between cells) or intracellularly (within a cell). Infection may be localized, involving a single cell or small area of the host plant, or it may be systemic, involving susceptible cells and tissues and spreading throughout the plant. Many pathogens (bacteria, viruses, viroids, nematodes, protozoa) reproduce within the host plant during the infection stage. Their populations increase rapidly and they are said to colonize the host.

Dissemination

Infectious diseases do not spread from plant to plant; pathogens do. Pathogen dissemination may occur via a number of agents, including wind, rain, irrigation water, insects, mites and other vectors, infested debris, infested equipment, animals, and humans (fig. 6.2) through the use of contaminated pruning shears, importation of infested plants, worldwide travel, disregard of quarantines, and transport of infested soil. Pathogens can survive in perennial plants and in infected plant parts, such as roots, bulbs, stems, and bud scales. Because annual hosts die at the end of the growing season, pathogens overwinter or oversummer in insect vectors, seeds, infested crop debris, weeds, soil, and fruit mummies, where they form resting structures until the next growing season, when susceptible annual hosts can be attacked again.

Figure 6.3 shows an example of key processes in the disease cycle of anthracnose diseases caused by several species of fungi. Inoculation, infection, common host symptoms associated with infection, pathogen dissemination, and overwintering are depicted. Many fungal diseases have similar disease cycles. The patho-

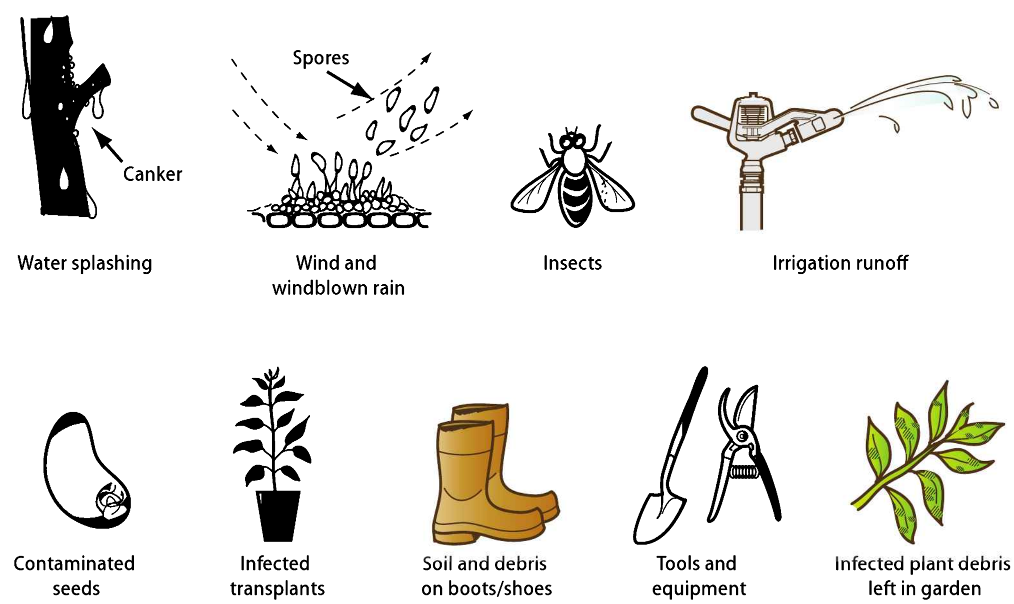
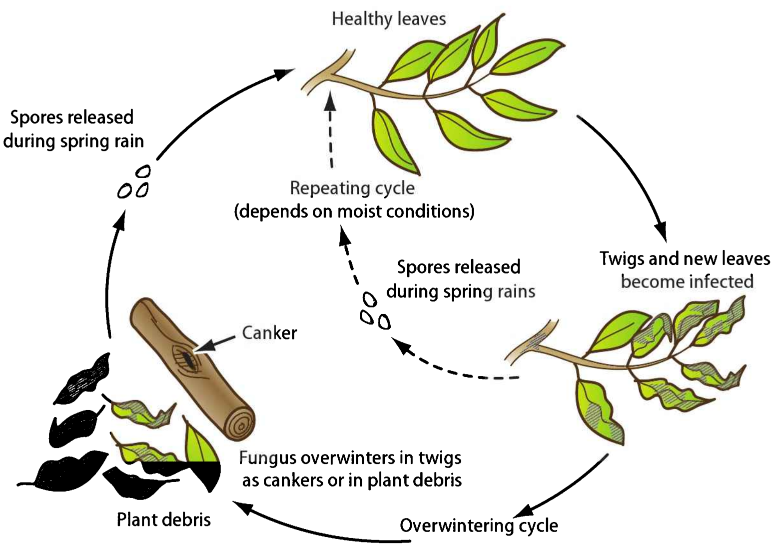


Figure 6.2

Common methods of disseminating plant pathogenic fungi and bacteria. *Source:* After Agrios 2005, p. 97.

Figure 6.3

Disease cycle of anthracnose diseases. *Source:* Crump 2009, p. 2.



gen's disease cycle is distinct from its life cycle, which refers to the growth of the pathogen from one generation to the next, from its immature to reproductive stages. A particular disease cycle may correspond closely to the life cycle of a particular pathogen, but the disease cycle refers to both the symptoms in the host plant and its interactions with the pathogen and may include a period within a growing season or extend from one growing season to the next. If more than one disease cycle occurs per growing season of the crop, the amount of inoculum multiplies many times.

The Infectious Disease Triangle

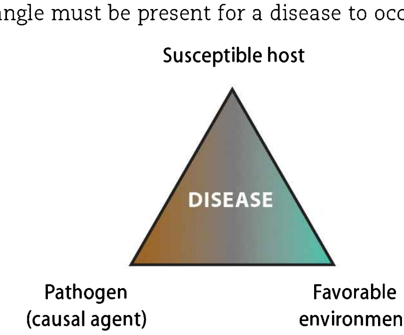
To summarize infectious disease principles, plant pathologists use a disease triangle (fig. 6.4), which depicts the compatible interactions of three essential components required for the development of an infectious disease: a pathogen in contact with the host, a susceptible host plant, and an environment favorable to the pathogen. An infectious disease will not occur if one of these components is missing.

- **Host**. Important host-related factors are the plant's overall health, developmental stage, and degree of susceptibility, tolerance, or genetic resistance to the pathogen. Some host plants may defend themselves against pathogen attack via structural features that act as physical barriers to pathogen entry and via biochemical reactions that produce substances toxic or inhibitory to pathogens. Both types of defenses may predate the attack of a particular pathogen or may be induced by pathogen attack.
- **Pathogen**. Factors affecting the pathogen's virulence (its ability to cause disease) include the size of its population, the degree to which it can contact the host, and the intensity with which it can parasitize the host plant. In some cases the particular strain or pathotype of the pathogen is an important consideration for this part of the disease triangle.
- **Environment**. Weather and soil conditions, especially temperature and moisture, are essential factors affecting the environmental component of the disease triangle. In general, most infectious diseases develop best when temperatures are warm and relative humidity is high. In other situations, free moisture is required for infection to take place. If weather conditions are too hot, too cold, or too dry, pathogens may be unable to mount an attack; a host plant susceptible under normal environmental conditions may be able to resist the pathogen under extreme environmental conditions.

The significance of the disease triangle as a visual representation of important

Figure 6.4

The plant disease triangle. All points of the triangle must be present for a disease to occur.



plant disease concepts is summarized in Agrios (2005, p. 79):

> Each side of the triangle represents one of the three components. The length of each side is proportional to the sum total of the characteristics of each component that favor disease. For example, if the plants are resistant, the wrong age, or widely spaced, the host side—and the amount of disease—would be small or zero: whereas, if the plants are susceptible, at a susceptible stage of growth, or densely planted, the host side would be long and the potential amount of disease could be great. Similarly, the more virulent, abundant, and active the pathogen, the longer the pathogen side would be and the greater the potential amount of disease. Also, the more favorable the environmental conditions that help the pathogen, (e.g., temperature, moisture, and wind) or that reduce host resistance, the longer the environment side would be and the greater the potential amount of disease. If the three components of the disease triangle could be quantified, the area of the triangle would represent the amount of disease in a plant or in a plant population. If any of the three components is zero, there can be no disease.

A proper understanding of the disease triangle concept makes it possible to devise effective control programs that include all three of the components. For example, a disease management program can first focus on the pathogen. Control options involve excluding or removing the pathogen using the following strategies:

- implement quarantine programs that seek to prevent introduction of a pathogen from one area to another
- treat seed to reduce or eliminate the presence of the pathogen on seed
- apply fungicides or soil fumigants to reduce pathogen inoculum that could contact host plants

Second, focus on the susceptible plant, or host. Possible control options include the following:

- plant a nonhost plant
- plant resistant or pathogen-tolerant cultivars
- use plants that are at a stage that is more tolerant to potential problems (e.g., planting transplants instead of direct-seeding)

Finally, implement control options that can create an environment that is favorable to the host plant but unfavorable to the pathogen. Examples include taking these measures:

- select appropriate planting dates
- choose planting sites that do not have a history of disease problems
- select sites with soil that drains well and is suitable for the plants to be used
- use proper irrigation methods (e.g., drip irrigation as opposed to overhead sprinkler irrigation)

Manipulating the environment may be achieved more completely in the greenhouse than under field or backyard conditions. Because pathogens can adapt to varying environmental conditions and selection pressures, they will be controlled more effectively by a combination of management measures than by a single control approach. The most effective disease control programs attack all three components in the disease triangle.

Causes of Infectious Plant Disease

Pathogens

A large number of organisms function as plant pathogens that cause infectious plant diseases. The majority are microscopic. The most common are fungi, bacteria, and viruses; also important are nematodes, parasitic seed plants, viroids, spiroplasmas, and phytoplasmas (formerly known as mycoplasma-like organisms). Visible pathogen structures on the surface of the host, such as a fungal mycelium (a

mass of hyphae that make up the body of a fungus), masses of spores, bacterial ooze, or nematodes with a spear-like stylet are called signs of disease. Pathogen signs are distinct from disease symptoms of the host plant, which are the visible manifestations of the effects of the pathogen on the host plant. Pathogens can

- interfere with photosynthesis by attacking leaves, defoliating plants, and reducing photosynthetic surface area
- attack roots and interfere with water absorption before any aboveground symptoms appear
- infect and plug up the vascular tissues (xylem, phloem, or both), which interferes with water transport or translocation of photosynthates (sugars) throughout the plant
- increase the respiration rate in infected plant cells
- alter the permeability of cell membranes
- alter the synthesis of proteins, including enzymes
- disrupt the metabolism of genetic materials (DNA/RNA) in infected host plants

Just as other organisms are divided into species, so are plant pathogens; however, the hierarchical terminology in recent usage has become complex and is not particularly uniform. As with all classification and taxonomic systems, genus and species names are sure to change; hopefully a more uniform and consistent system will continue to develop for classifying plant pathogens. Certain individuals of a fungus species that attack only certain host crops are designated as varieties or special forms (*forma specialis*, or f. sp.). For example, the *Fusarium oxysporum* pathogen that infects only celery is known as *Fusarium oxysporum* f. sp. *apii*. Likewise, many species of pathogenic bacteria consist of strains that differ primarily in the host plant species they infect and are known as pathovars (pv.). The citrus canker bacterial pathogen infects only citrus and is therefore named *Xanthomonas axonopodis* pv. *citri*. Within each special form or variety of pathogenic fungus, some individuals, known as a race, attack only certain varieties of the host plant. Variants of a fungus race can evolve when they develop the capability of infecting host varieties that they could not infect previously. Asexual progeny of a variant are known as a biotype. Each race can consist of several biotypes. In viruses, pathologists usually refer to strains rather than races.

Fungi

Fungi are the single most important cause of plant diseases. Of the 100,000 known species of fungi, more than 10,000 can cause diseases in plants. All plants are attacked by some types of disease-causing fungi. Some of these pathogenic fungi have a very wide host range, while others are specialized and will infect only one plant species. Fungi damage susceptible plants by producing toxins and enzymes that disrupt normal plant growth and physiology. In contrast, only about 100 species of fungi cause diseases in humans and animals.

Until recently, the important pathogen group called Oomycetes was included in this large group of fungal pathogens. However, researchers have discovered that Oomycetes are actually more closely related to the brown algae group of organisms. Plant pathologists therefore now designate Oomycetes as fungal-like organisms. For practical purposes, however, this handbook will refer to these organisms as fungi. Important Oomycete pathogens in California include the downy mildews, *Phytophthora* spp., and *Pythium* spp.

The majority of fungus species are saprophytes that feed on dead organic matter and are beneficial to the environment. Some saprophytes are beneficial because they use toxic chemicals as food and, as a by-product of their metabolism, degrade the toxics to simpler chemicals that are nontoxic to people. Other saprophytes are beneficial because they feed on decaying plant residues left in the soil after harvest,

Table 6.1.

COMMON DISEASE SYMPTOMS ASSOCIATED WITH PLANT-PATHOGENIC FUNGI

Disease	Symptoms
anthracnose	Necrotic and sunken, ulcer-like lesion on the stem, leaf, fruit, or flower of the host plant; often called leaf, shoot, bud, or twig blight; infects trees (ash, elm, oak, sycamore) and shrubs throughout the United States.
basal stem rot	Disintegration of the lower part of the stem.
blight	General and extremely rapid browning of leaves, branches, twigs, and flower organs, resulting in their death.
canker	Localized wounds or necrotic lesions, often sunken beneath the surface of a stem or branch of a woody plant.
damping-off	Rapid death and collapse of seedlings in the seedbed or field; found worldwide in tropical and temperate climates in forest soils, valleys, greenhouses, and backyards.
decline	Plants growing poorly; small, brittle, yellowish or red leaves; defoliation and dieback.
dieback	Extensive necrosis of twigs beginning at their tips and advancing toward their bases.
downy mildew	Yellow to brown spots on upper leaf surfaces; fuzzy spore growth, primarily on lower leaf surfaces, especially after rain or heavy fog; requires high relative humidity and cool weather; primarily a problem on a few vegetable crops in California.
dry rot	Maceration and disintegration of fruit, roots, bulbs, tubers, and fleshy leaves.
galls	Enlarged tumorous overgrowths on host plant.
leaf curls	Distortion, thickening, and curling of leaves.
leaf spots	Localized lesions on host leaves consisting of dead, collapsed cells.
powdery mildew	Chlorotic (yellowed) or necrotic areas on leaves, stems, and fruit; infected leaves, stems, and fruit are usually covered with whitish-colored mycelia, and spore-containing fungus structures, which look powdery (an exception is powdery mildew on tomatoes, eggplants, and peppers, which produces yellow patches on leaves often without powdery mycelia). Disease affects many landscape plants, vegetables and fruit trees; does not require high relative humidity (unlike downy mildew) and can establish and thrive under the warm, dry conditions of the California summer.
mold	Profuse, woolly fungus growth on host tissue (signs).
root rot	Disintegration or decay of part or all of the host root system.
rust	Numerous, small, rust-colored pustules (spore masses) on leaves or stems. Rusts have caused famines due to destruction of cereal grains; also infect birch, cottonwood, fuchsia, hawthorn, pine, juniper, rose, rhododendron.
scab	Localized lesions on host fruit, leaves, tubers, usually slightly raised or sunken and cracked, giving a scabby appearance.
shot hole	Holes on affected leaves; discolored spots on buds, leaves, shoots, and fruit; infects *Prunus* spp. (almond, apricot, plum). First appears as reddish, purplish, or brown spots about $^{1}/_{10}$ inch in diameter on new buds, leaves, and shoots; spots expand and centers turn brown; centers of spots on leaves often fall out, leaving holes (most holes on leaves are caused by chewing insects but not these spots). More severe after warm, wet winters.
soft rot	Maceration and disintegration of fruit, roots, bulbs, tubers, and fleshy leaves.
sooty mold	Sooty coating on foliage, stems, and fruit formed by dark fungal mycelia that live in the honeydew secreted by insects, such as aphids, mealybugs, scales, and whiteflies (signs of disease).
smut	Characterized by masses of dark, powdery spores (signs).
wilt	Droopy leaves or shoots due to disturbances of the host's vascular system (food- and water-conducting tissues) in roots or stems. Fungi grow primarily in the host's vascular system and plug it up, preventing the flow of water and nutrients to leaves and shoots, which results in secondary wilting symptoms.
witches'-broom	Profuse upward branching of twigs.

Source: Adapted from Agrios 2005, pp. 397–398.

Note: For photographs and further information, see the UC IPM website, ipm.ucdavis.edu/, and the UC IPM manuals listed in the bibliography.

decompose them, and recycle them into useful products such as humus (soil organic matter that resists further decomposition and improves soil structure and fertility) and plant nutrients (simple forms of minerals that are absorbed by plants) (see the section on soil organic matter in chapter 3, "Soil and Fertilizer Management"). Other beneficial fungi live in association with plant roots (e.g., mycorrhizae) and may synthesize plant growth–regulating hormones beneficial to growth, yield, and resistance to pathogens.

Pathogenic fungi usually grow on or through diseased plant tissue as fine, threadlike structures called hyphae that form a network known as a mycelium, the fungus body. Fungi are microscopic, but when many hyphae aggregate to form a mycelium, the fungus can become macroscopic, visible to the unaided eye. Fungi usually reproduce and multiply by means of spores, specialized reproductive bodies analogous to seeds. Fungal spores are usually produced at or near the surface of host tissues, ensuring prompt, efficient pathogen dissemination. Fungal spores can be spread by wind, irrigation or rainwater, insects, tools, birds, movement of soil, or anything that the spores contact. When spores land on a susceptible host plant and environmental conditions are favorable, they germinate to produce new fungal mycelia. Often, the mycelia include haustoria, specialized structures used to pierce and penetrate host tissue and to absorb host nutrients for their own growth. Fungi can also attack their hosts through wounds and natural openings, such as stomata.

Fungi have numerous mechanisms for survival. They can overwinter or oversummer by producing various survival structures that are designed to withstand periods of dryness, high temperatures, or the absence of a plant host. Such structures include sclerotia (compact masses of hyphae), rhizomorphs (root-like masses of hyphae), or various types of thick-walled spores (oospores, teliospores, zygospores). Management of fungal diseases, discussed at the end of this chapter, can involve cultural practices, host resistance management, and fungicides (chemicals that kill fungi).

Common disease symptoms caused by pathogenic fungi are given in table 6.1. Some of these symptoms—smuts, molds, sooty molds, and powdery mildews—are caused only by pathogenic fungi. These kinds of symptoms and the signs associated with them are critical to identifying and diagnosing the pathogenic fungi that cause the disease. Other symptoms listed in table 6.1—galls, cankers, leaf spots, leaf curls, scabs, blights, soft rots, and root rots—are typical of both pathogenic fungi and bacteria. When disease symptoms are not specific, identification of the offending pathogen is more difficult and requires additional analysis. A hand lens, which can magnify characteristic fungal structures (signs), may aid in a cursory identification process in the field. To confirm identification and diagnosis, fungi often must be analyzed in plant pathology labs by staff trained in sterile techniques for isolating pathogens from diseased host tissue. Special nutrient media are used for growing the pathogen in culture, and the pathogen's biochemistry and morphology (spore shape, spore-bearing structure arrangement, colony characteristics) are studied to enable accurate identification and to recommend control measures. The following sections briefly describe some very important groups of fungal pathogens.

Phytophthora

In California, there are two groups of *Phytophthora* pathogens. The first group consists of species that are strictly soilborne and primarily cause root and crown diseases. For example, *Phytophthora cinnamomi* causes root rots of many hosts, including avocados, azaleas, oaks, and other ornamental plants. Two other species, *P. citrophthora* and *P. parasitica*, infect citrus and cause trunk lesions (gummosis) and root rots; *P. citrophthora* can also cause

fruit rots (brown rot) if inoculum from soil is splashed up onto fruit. The second group of *Phytophthora* pathogens consists of species that are primarily foliar pathogens. Late blight, mentioned earlier, is a disease caused by *P. infestans* and results in severe foliar infections of potato and tomato. Sudden oak death (SOD) is the destructive disease caused by *P. ramorum*; this recently described problem is causing trunk and branch cankers and foliar blights of many forest and nursery species. These diseases are favored by high soil moisture, high relative humidity, free moisture on foliage, and cool temperatures.

Armillaria

Armillaria mellea causes root rots on a wide variety of plants, including almonds, walnuts, apples, citrus, grapes, peaches, strawberries, and many ornamental trees and shrubs. During the winter, *Armillaria* often forms clusters of mushrooms at the bases of infected plants. *Armillaria* survives for very long periods in soil by producing rhizomorphs.

Fusarium and Verticillium

Fusarium oxysporum and *Verticillium dahliae* are the primary causes of vascular wilts in many ornamental, fruit, and vegetable plants. Symptoms of infected plants include wilting of young shoots and leaves, yellowing and eventual browning of leaves on one side of the plant or branch, and eventual death of branches and possibly the entire plant. By cutting into the xylem tissues of affected branches and stems, one can observe the brown to black vascular discoloration caused by these two pathogens.

Taphrina

Diseases caused by *Taphrina* spp. are often found on backyard stone fruit crops, especially peach and nectarine. Peach leaf curl disease results in greatly deformed and twisted leaves, as well as fruit infections. Other *Taphrina* spp. cause leaf blister diseases of oak and poplar.

Powdery mildews

The term *powdery mildew* refers to fungal pathogens as well as to the diseases they cause. Powdery mildews are caused by a number of closely related species and are probably among the most easily recognizable plant diseases. These pathogens infect ornamentals, fruit trees, strawberry, vegetables, cereals, forest species, and weeds. Characteristic signs of the fungus are the patches of white to grayish powdery growth on leaves and stems.

Downy mildews

The term *downy mildew* refers to fungal pathogens as well as to the diseases they cause. These pathogens require cool, humid conditions and cause leaf spots on a number of vegetable and ornamental plants. Downy mildew signs are usually on the underside of leaves, where white, gray, or purple fungal growth can be seen.

Rusts

Rust pathogens appear as orange, brown-orange, or brown-black pustules developing on leaves. Severe rust results in drying out and death of plant leaves.

Pythium and Rhizoctonia

Commonly encountered in backyard gardens, *Pythium* and *Rhizoctonia* are the two most common fungal pathogens that cause damping-off diseases of seeds and seedlings. Resident in the soil, these pathogens infect seeds, germinated seedlings, and newly placed transplants. Infection results in seed and seedling death and poor stands.

Molds

Penicillium fungi cause two postharvest diseases of citrus: blue mold and green mold. *Rhizopus*, the common bread mold fungus, causes soft rots of many fleshy fruits, vegetables, bulbs, and corms. Worldwide, *Botrytis* diseases are one of the most common, widely distributed problems of vegetables, ornamentals, fruits, and field crops. Called gray mold, this pathogen can be particularly serious on grapes, strawberries, lettuce, and various flowers.

Bacteria and Other Prokaryotic Plant Pathogens

Of the 1,600 species of bacteria identified to date, about 100 cause diseases in plants. The vast majority of bacterial species are beneficial soil saprophytes that decompose organic matter, improving soil fertility and recycling nutrients, making them available to plants in mineral form. Some bacterial species cause diseases in humans, such as tuberculosis, typhoid fever, and bacterial pneumonia. Each plant-pathogenic species may consist of numerous pathovars (pv.) differing mainly in the host plant species they infect.

Bacteria are microscopic, one-celled prokaryotes (single-celled organisms whose genetic material is not organized into a nucleus). Plant-pathogenic bacteria are rod shaped, spherical, spiral, filamentous, or threadlike and have a rigid cell wall. The cell wall may be surrounded by a thin, gummy material known as a slime layer, or it may be surrounded by a thick, gummy material known as a capsule. Most plant-pathogenic bacteria have delicate, threadlike flagella that project from the cell and enable the bacteria to move. Bacteria enter host plants through wounds or natural openings and use susceptible crop plants for their source of food. Bacteria multiply rapidly, reproducing by fission, in which one bacterium simply divides into two bacteria, which then divide into four bacteria, which divide into eight bacteria, and so on. The population can grow rapidly. Under favorable environmental conditions, many bacteria species can divide every 20 minutes. At this doubling rate, one bacterium could have more than a million offspring in less than half a day. The progeny of a single bacterium are known as a colony. Under the microscope, the colony may look circular, oval, or have an irregular shape and may be a fraction of a millimeter to several centimeters in diameter. Warm temperatures and high relative humidity (moisture) are required for bacteria to multiply; thus, they are not as serious as fungal pathogens in most areas of California. However, sprinkler irrigation can lead to bacterial problems, even in dry areas.

Bacterial inoculum is mostly spread by splashing water and rain, but it can also be windblown, carried by insects, or moved by humans on contaminated hands, tools, and soil (fig. 6.2). Bacteria can survive for many months in a dormant state (overwinter or oversummer) in host tissues, such as in seeds, storage organs, cankers, and plant debris, or in the intestines of the insects that carry them to their hosts.

Plant-pathogenic bacteria cause many types of disease symptoms that are similar to those caused by pathogenic fungi (see table 6.1). Common symptoms of bacterial diseases are

- spots on leaves, stems, blossoms, and fruits
- rapidly advancing necroses of these organs (blights)
- soft rots of fruits, roots, and other storage organs
- scabs
- vascular wilts
- galls
- cankers on stems and tree trunks

Bacteria cause wilts when they plug up the water-conducting vascular system of the host. Necrotic blights are characterized by rapidly expanding areas of dead and discolored tissue on stems, leaves, and flowers. Soft rots of fleshy storage organs (e.g., potatoes) result in soft, runny decomposition of the stored plant commodity. Bacterial galls are deformed growths resembling tumors at the bases of crowns or stems.

Bacteria that cause some of the more common plant diseases in California are species of *Agrobacterium, Clavibacter, Erwinia, Pseudomonas, Streptomyces, Xanthomonas*, and *Xylella*. Figure 6.5 gives the disease cycle of fire blight, caused by *Erwinia amylovora*, infecting apple and pear trees in the orchard and ornamental

apples and pears in the landscape. Landscape and garden plants closely related to apples and pears, such as firethorn, loquat, and hawthorn, can also be seriously injured by the disease. Note the complex interactions among bacteria populations, insects, rain, host flowers, twigs, leaves, and overwintering structures in the disease process. The bacteria overwinter in cankers on the tree. Inoculum is carried by wind, rain, and insects. The first symptom is blossom blight, with flowers initially appearing water soaked, then shriveled and brown. The bacteria move from the infected flower into the fruit, spurs, and twigs. The disease intensifies as shoot tips become blighted and turn black, as if scorched by fire. Pathogen movement slows in woody branches. *Erwinia* bacteria form cankers that will initiate the next infection cycle.

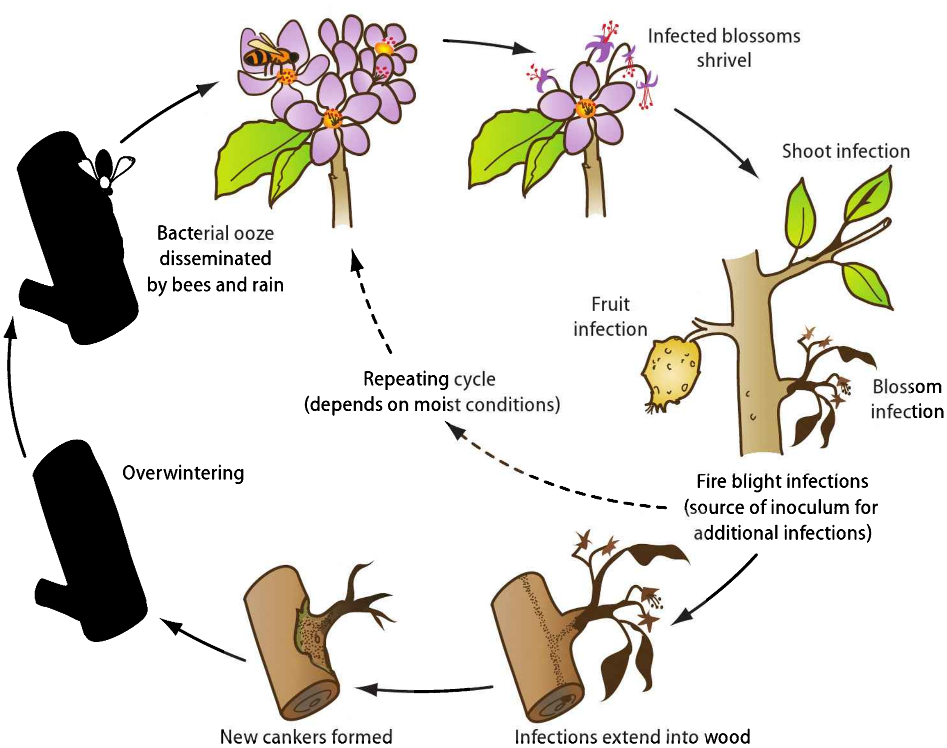
Mechanisms by which bacteria damage plants include the production of toxins, gums, enzymes, and growth hormones that disrupt healthy plant function.

Phytoplasmas

Phytoplasmas (formerly known as mycoplasma-like organisms, or MLOs) are microscopic prokaryotes that are similar to bacteria except that they lack a cell wall and flagella. They are smaller than bacteria, larger than viruses, and appear in various shapes such as spheres, cylinders, and constricted chains. Phytoplasmas that cause plant diseases are similar to mycoplasmas that can cause respiratory and urogenital diseases in humans and animals. Phytoplasmas were first recognized as plant pathogens in 1967 and were called MLOs. More than 200 plant diseases, some of which are important diseases of fruit trees, are now known to be caused by phytoplasmas. They are transmitted primarily by insect vectors (mostly leafhoppers and a few psyllids) and by grafting. The insect vectors cannot transmit phytoplasmas immediately after feeding on an infected plant because the incubation period varies with temperature and may range from 10 to 45 days. During this period, the phytoplasmas multiply in

Figure 6.5

Disease cycle of fire blight of pear and apple caused by *Erwinia amylovora*. *Source:* Teviotdale 2011, p. 2.



the insect vectors. When the concentration of phytoplasmas in the salivary glands of the infected insects is high enough, the insects are then capable of injecting the pathogens into susceptible host plants via their mouthparts and retain this capability for the rest of their lives.

Phytoplasmas invade primarily the food-conducting elements (phloem) of the host's vascular system and disrupt its normal function. Phytoplasmas induce disease symptoms that are quite similar to those caused by viruses: yellowing, leaf curling, twisting of stems, progressive weakening of the host, stunting, and reduced yields. Common phytoplasma-caused diseases that can occur in California are pear decline, peach yellows, aster yellows (on carrots, onion, celery, lettuce, spinach, potato, aster, gladiolus, and phlox), elm phloem necrosis, and big bud of tomato. Phytoplasmas can overwinter in weeds such as dandelions and wild carrots. The insect vectors play a role in transporting the phytoplasmas from infected weeds to healthy plants.

Phytoplasmas can be suppressed in plant tissue by heat treating the material in growth chambers or by immersing dormant organs in hot water for 10 minutes at 120°F or for 3 days at 85°F. Although not available to backyard gardeners, antibiotics (e.g., terramycin, aureomycin, erythromycin, chloramphenicol) have been documented to suppress phytoplasma diseases; however, the symptoms usually reappear if the antibiotic treatment stops. On diseased trees, antibiotics are applied by direct injection into the trunks. Treatments must be reapplied annually or biannually to diseased trees to be effective. Most phytoplasmas are completely resistant to penicillin.

Spiroplasmas

Spiroplasmas are helical-shaped prokaryotes that are very similar to phytoplasmas but distinct from them primarily in that they can be cultured on nutrient media and have a spiral shape. Spiroplasmas cause a number of important diseases in susceptible corn and citrus trees, such as citrus stubborn disease *(Spiroplasma citri)* and corn stunt. Citrus stubborn disease is one of the worst threats to production of sweet oranges and grapefruit in California because diseased trees produce significantly fewer fruit and the fruit are smaller. Detection is difficult, and the spread of disease is insidious. The pathogen infects the phloem and can be transmitted by budding, grafting, and leafhoppers. Control depends on the use of disease-free scion wood and rootstocks, removal of infected trees, and detection of the pathogen by nucleic acid–based methods (polymerase chain reaction, or PCR) or culturing. Experimental antibiotic treatments of tree trunks have not proven effective in controlling the disease.

Fastidious vascular bacteria

Fastidious vascular bacteria (formerly known as rickettsia-like organisms) are a type of plant-pathogenic bacteria first identified in 1972, almost a century after bacteria were identified as pathogens that cause plant disease (1882). Their relationship to other plant-pathogenic bacteria is not well understood. Previously thought to be rickettsia-like organisms, they are rod-shaped bacteria transmitted to susceptible plant hosts by insect vectors such as leafhoppers, sharpshooters, and psyllids. Some fastidious vascular bacteria infect the phloem of their host plants, causing symptoms such as leaf stunting and clubbing, shoot proliferation, witches'-broom, and greening of floral parts. Others infect the xylem, causing symptoms such as marginal leaf necrosis, internal discoloration, and important xylem-limited diseases such as Pierce's disease in grapes and leaf scorch in oleander caused by *Xylella fastidiosa* (the same or a closely related bacterium is suspected of causing a leaf scorch disease of several tree species in California, including sweetgum and olive). Insect vectors can acquire and transmit

some of these bacteria in less than 2 hours. Experimentally, some plants infected with fastidious vascular bacteria respond favorably to injections of antibiotics in the tetracycline group, though injections must be repeated annually.

Viruses

Viruses differ from other plant pathogens in that they are not made up of cells, do not divide to increase their population, and can be seen only with the aid of an electron microscope. Viruses consist of a DNA or RNA core (genetic material comprised of nucleic acid) surrounded by a protein coat known as a capsid (a protective sheathing of amino acids) and are known as DNA viruses or RNA viruses, respectively. The nucleic acid of the majority of viruses that infect plants is RNA, but at least 25 plant-pathogenic viruses contain DNA. Individual virus particles are known as virions. Viruses do not produce any specialized reproductive structures such as spores or seeds. Instead, they reproduce and multiply by inducing the host plant to manufacture more virus particles. Once inside the host plant, viruses take charge, disrupting normal plant function. Viral DNA or RNA orders the DNA of the host plant to manufacture virus DNA or RNA, which the virus needs to make more virus particles, and the host plant begins to show symptoms of disease as a result of abnormal plant metabolism and physiology induced by the viral infection. For example, viruses can cause a decrease in photosynthesis, a decrease in the level of carbohydrates in host tissues, a decrease in nitrogen levels, and a decrease in the concentration of plant hormones, as well as the synthesis of viral RNA or DNA. Plant-pathogenic viruses do not contain any enzymes, toxins, or other substances involved in the pathogenicity, but some viruses can lyse (decompose or destroy) host plant cells. Viruses take up space in host plant cells and wreak havoc on the normal order of plant metabolism and physiology.

About one-fourth of the more than 2,000 known viruses attack and cause diseases in plants. In addition to viruses that attack plants, some viruses attack humans and animals and cause diseases such as influenza (flu), polio, smallpox, rabies, and warts. Other viruses attack fungi, bacteria, and phytoplasmas. No viruses that cause disease in plants are known to cause disease in humans.

The vast majority of viral infections in plants are systemic, occurring throughout the host plant as the virus moves from cell to cell, but symptoms may be localized, as with necrotic lesions that develop only at the point of virus entry into the plant. Once a plant is infected by a systemic virus, it will usually remain infected its entire life (chronic infection). Symptoms caused by a given virus may vary greatly depending on the host. A virus that causes severe symptoms in a tomato plant, for example, may cause little or no obvious symptoms on a verbena plant, although the virus accumulates to similar levels within each plant. Symptoms commonly associated with systemic viral diseases are mosaics (light green, yellow, or white areas intermingled with the normal green color of the foliage or color of the fruit); flower break (disruption of color pigments in flowers causing stripes, spots, or dilution of normal color), ring spots (chlorotic or necrotic rings or patterns on leaves, stems, or fruit); and overall stunting and reduced growth rate. Depending on symptom severity, mosaic-type symptoms may be described as mottling, streaking, vein clearing, or vein banding. Mosaics, mottles, and ring spots are not associated exclusively with viruses; they are also associated with nutrient deficiencies or toxicities. Other symptoms associated with viruses are leaf curling, leaf rolling, yellowing (chlorosis), tumors, stem pitting, or malformation of plant parts. Virus-infected flowers may fail to open properly or be otherwise deformed. Infected fruit may be small and poorly shaped, and yield will be reduced.

Many plant-pathogenic viruses have a wide host range, and more than one virus may infect a plant simultaneously. Viruses can enter plant cells through wounds or can be injected by vectors such as plant-feeding insects, mites, fungi, and nematodes when they feed. When a vector contains a virus and is capable of transmitting it to a host, the vector is said to be viruliferous. The most common means of virus transmission from infected to healthy plants is by insect vectors, primarily aphids, whiteflies, and leafhoppers; these vectors have piercing and sucking mouthparts and are in the insect order Homoptera. Aphids are the most important vectors of plant viruses, which they carry on their stylets (stylet-borne, or nonpersistent, viruses) or accumulate in their guts and transmit to host plants via their mouthparts when they feed (circulative, or persistent, viruses). Aphids transmit the majority of stylet-borne viruses, which they can acquire after feeding on a diseased plant for 30 seconds or less and can transmit to a healthy plant after feeding on it for a few seconds. After acquiring a stylet-borne virus, aphids may remain viruliferous for a few minutes to several hours. Although aphids cannot transmit circulative viruses immediately after feeding on a virus-infected host, once they do become viruliferous, which can take several hours, they are capable of transmitting the virus for several days. Aphids can spread virus pathogens relatively long distances when they are carried by prevailing winds.

Leafhopper-transmitted viruses are circulative and typically cause disturbances in the phloem, disrupting the transport of photosynthates in the host plant. After acquisition feeding on an infected host, leafhoppers may take up to 2 weeks to become viruliferous, but then they can remain viruliferous for the rest of their lives. Whitefly-transmitted viruses are either circulative or semipersistently transmitted. They are particularly problematic in semiarid and tropical areas of the world.

Viruses often found in gardens and backyard plantings are also transmitted by insects without piercing and sucking mouth parts, especially thrips. Two commonly encountered viruses, tomato spotted wilt virus (TSWV) and impatiens necrotic spot virus (INSV), are found throughout the world and can infect hundreds of plants in different plant families. Both diseases cause a broad range of symptoms, including stunting, poor growth, leaf and flower spots, necrotic pitting, ring spots, leaf and petal deformities, and other symptoms. TSWV and INSV are vectored only by the thrips insect. Because the viruses have extremely large host ranges and thrips are very difficult to control or exclude, the diseases caused by these viruses can result in significant damage.

A very important means of virus transmission in many ornamental trees, shrubs, perennial flowers, and fruit crops is via infected vegetative propagation materials, which include stems, branches, and buds used for grafting, as well as producing cuttings and other asexual propagation techniques. If such materials already contain viruses, their use in propagation will transmit the pathogens to the resulting new plants. Viruses can also be transmitted via infected pollen grains, ovules, and seeds. Viruses are also spread to healthy plants by virus-infected fungi, mites, nematodes, parasitic seed plants (dodder), natural root grafts, and cultural practices, including the use of contaminated equipment.

Pathogens similar to viruses are viroids, which are naked (lacking a protein coat), single-stranded, circular RNAs that can cause plant disease by themselves. The symptoms caused by viroids are generally the same as those caused by viruses, listed above. The 30 known viroids are usually somewhat host specific and have narrow host ranges, although some may be able to infect plants in different genera. Common viroids infect chrysanthemums, avocado, citrus, tomatoes, and potatoes.

In addition, other pathogens called sat-

ellite viruses can be associated with viruses and can affect viruses' ability to multiply and cause disease. Virusoids are similar to viroids and can be present inside typical RNA viruses; together they infect the plant host. Satellite RNAs may be found in the virus particles of certain viruses, but they may be related to the RNA of the virus or the host plant. Generally, they reduce the effects of viral infection and may represent a protective response by the host to fight viral infection.

Nematodes

Plant-parasitic nematodes are microscopic, unsegmented, aquatic roundworms invisible to the unaided eye that usually dwell in the soil and feed on plant roots; however, some species do feed on aboveground plant parts, such as stems, buds, leaves, or bulbs. Nematodes should not be confused with segmented earthworms, which are beneficial to soil structure and fertility, as discussed in the "Soil Organic Matter" section of chapter 3. However, not all nematodes are plant pathogenic. Some are considered beneficial in that they feed on microbes and debris in the soil, and some are able to attack insect pests and are marketed as biological control agents. Other nematodes are able to cause disease in humans and animals.

Many diseases once thought to be caused by fungi, viruses, or soil deficiencies are now recognized as the work of nematodes. Some common plant-parasitic nematode groups are root knot nematodes (*Meloidogyne* spp.), citrus nematode (*Tylenchulus semipenetrans*), cyst nematodes (*Heterodera* spp. and *Globodera* spp.), root lesion nematodes (*Pratylenchus* spp.), and stem and bulb nematodes (*Ditylenchus* spp.). Gall-like overgrowths (knots) on roots are characteristic symptoms of root knot nematodes, but these symptoms are not diagnostic because affected plants do not always develop noticeable galls, and similar symptoms can be caused by problems other than nematodes.

Nematodes directly penetrate plants by using their sharp mouthparts, called stylets, which are like hypodermic needles, to repeatedly puncture and pierce through the roots of their hosts. Pathogenic nematodes then secrete a saliva-like substance that contains enzymes that digest the nutrients of the plant root tissue. Next, they suck up the host plant's nutrients for their own use, thereby weakening and stressing the plant. Typically, nematodes do not kill their hosts, but, by causing wounds in the root system and reducing their vigor, they predispose the host's roots to diseases. Bacterial, viral, and fungal pathogens can invade these nematode-weakened, infected, and mechanically wounded roots, compounding the direct damage caused by the nematodes themselves. Nematodes can transmit viruses to healthy plants via their stylets for up to several months after they have fed on a virus-infected host. Some nematodes function as endoparasites (they completely enter the host's roots and feed from within the root tissue); others function as ectoparasites (they do not enter the roots, but feed on the host's cells near the root surfaces).

Nematodes induce a variety of disease symptoms, such as root galls, root knots, root lesions, excessive root branching, injured root tips, and general stunting, yellowing, and distortions of whole plants. Nematode infestation impairs root uptake of water and minerals from the soil. As a result, plants wilt, become yellowed, and develop symptoms indicative of root problems similar to those associated with drought injury, mineral deficiencies, or root rots caused by fungal pathogens.

When plant-parasitic nematodes form complexes with soilborne plant-pathogenic fungi (e.g., *Fusarium, Verticillium, Pythium, Rhizoctonia,* and *Phytophthora* spp.), susceptible plants are damaged more than would be expected from each organism alone. In these cases, the nematodes do not transmit the fungus, but plants already infested by the nematodes have

much worse symptoms from the fungal infection. Varieties normally resistant to the fungi can become susceptible after infestation by nematodes. One example of a nematode-fungal complex is potato early dying disease, caused by *Verticillium dahliae* and *Pratylenchus penetrans*. Few nematode-bacterial complexes are known. Nematodes can also serve as vectors of plant-pathogenic viruses such as grape fanleaf virus and tobacco rattle virus.

Warm, moist soil conditions favor the nematode life cycle, which may be completed in 3 to 4 weeks (egg to egg) under optimal environmental conditions. Females lay eggs that hatch to young larvae that are shaped like adult nematodes. The larvae undergo four larval stages before they become adults. Populations may build rapidly, but unlike with other pests, initial nematode infestation does not spread rapidly. Nematodes normally move only a foot or so during the growing season, traveling by swimming in and through the water on soil particles and plant roots. Nematode populations are typically localized to a relatively small area of a garden or field. Nematodes can survive (overwinter and oversummer) for a year or more in soil as eggs in the absence of a susceptible host. Eggs can be loose in the soil or contained within protective cysts (the dried body of the adult female of some species). Plant-parasitic nematodes can be disseminated from one place to another on infested plant parts and cultural implements, contaminated soil, animals, or even dust.

Parasitic Seed Plants

Higher plants that depend on other plants for their food are known as parasitic seed plants. Of the more than 2,500 species known, few cause important diseases on agricultural crops or forest trees, but some of these parasites—dodder, mistletoe, witchweed, and broomrape—are parasitic to crop plants. Parasitic seed plants produce flowers and seed just like the plants they parasitize, but they depend on their hosts for water and mineral nutrients. Parasitic seed plants enter their hosts via direct penetration; they pierce the plant surface by mechanical force and use their haustoria to steal water and nutrients from the host. Parasitized plants or plant parts (e.g., tree branches) lose vigor and may eventually die. Parasitic plants attack perennial and annual plants and spread via their seed.

Dwarf mistletoes of conifers

The dwarf mistletoes (*Arceuthobium* spp.) are a very serious pathogen of western conifers such as pines, firs, spruce, and hemlock. Infected branches develop swellings and cankers. Dwarf mistletoes can produce shoots, inconspicuous leaves, flowers, and fruit that become turgid at maturity. The fruit release their seed forcibly, sometimes up to a distance of 50 feet. The seed are covered with a sticky substance that enables them to adhere to whatever they contact. Dwarf mistletoes are controlled by physically removing the pathogens.

Leafy mistletoes

Leafy mistletoes (*Phoradendron* spp.) produce large, nearly oval leaves and may infect woody perennials such as apple, citrus, cherry, black walnut, ash, alder, birch, oak, and maple. European mistletoe *(Viscum album)* is present only in Sonoma County and infects primarily alder, apple, black locust, cottonwood, and maple trees. Leafy mistletoes produce sticky seed disseminated mainly by birds that eat the seed. If seeds drop on a susceptible tree, they may germinate and colonize the host. An otherwise healthy tree can tolerate a few mistletoes, but individual branches may die. Pruning infested branches promptly can suppress leafy mistletoes. Planting species that appear to be resistant is another control strategy. Chinese pistache, crape myrtle, eucalyptus, ginkgo, golden rain tree, liquidambar, persimmon, sycamore, and conifers are rarely infested.

Dodder

A slender, twining plant, dodder (*Cuscuta* sp.) produces a dense, tangled mat of yellow or orange strands that entwine and spread over host plants such as tomatoes, alfalfa, cantaloupe, flax, onion, and sugarbeet. Dodder seed overwinters in the soil, where it germinates and enters the host tissue. Control of dodder can be difficult. Recommended control measures include the use of dodder-free seed and selected herbicides.

Broomrape

Broomrape *(Orobanche ramosa)* is a parasite of tomato in California. Clubs of whitish-yellow to blue stems arise from the ground at the base of the host plant. The seed germinate only in the presence of a susceptible host. It can overwinter and survive in the soil for more than 10 years. Soil fumigation can control this parasitic plant.

Basic Concepts and Principles of Noninfectious Plant Disease

Environmental Factors That Cause Noninfectious Plant Disease

The common trait of noninfectious diseases is that they are caused by a lack of, excess of, or extremes in an important environmental component that supports plant growth and development. Nutritional deficiencies, mineral excesses, air pollution, overdoses of pesticides, lack of or excessive moisture, extremes in temperature, excessive wind, and extremes in light duration and quality can cause noninfectious disease in plants. Many of these diseases result from human activity or neglect. Because these diseases occur in the absence of pathogens, they cannot be transmitted from diseased to healthy plants and are therefore not contagious. Damage caused by noninfectious agents can be as serious as damage caused by pathogen-induced diseases and may mimic symptoms associated with fungi, bacteria, and viruses.

Most of the disorders in home gardens and landscapes are caused by noninfectious environmental factors. Plants killed or damaged by noninfectious diseases can be overrun by secondary infectious organisms, compounding the difficulty of diagnosing the causal agent. The disease triangle (see fig. 6.4) shows that prevailing environmental factors—temperature, moisture, light, soil nutrient status, and soil pH—can affect the development of pathogen-mediated, infectious plant diseases. After a pathogen comes into contact with a susceptible host, prevailing environmental conditions or stresses can increase or reduce host susceptibility or pathogen virulence and thus may even determine whether an infectious disease will occur. In addition, microclimates (the environment of an individual plant or portion of a plant) may vary, making only some plants susceptible; for example, wet patches in a garden cause patchy disease distribution.

Below are summaries of the most common environmental factors causing noninfectious diseases. Additional details of these types of plant problems in landscape plantings can be found in *Abiotic Disorders of Landscape Plants* (Costello et al. 2003).

Levels of moisture and relative humidity

Moisture imbalance in the soil (a lack of soil moisture or excessive soil moisture) is the single most important environmental factor in noninfectious diseases. Moisture may take the form of rain, dew, irrigation water on plant surfaces or around roots, or relative humidity in the air. Overly moist, saturated soil caused by poor drainage, flooding, or overirrigation can suffocate roots and enhance root diseases because of a lack of oxygen. Many fungal root pathogens also thrive in overly wet soil. Plants wilt, leaves become chlorotic, and plants may even die. Drought, on the other hand, can also cause disease symptoms

such as chlorosis, wilting, stunting, yield reduction, desiccation, and death. Plants weakened by drought are more susceptible to infection by certain pathogens.

Low relative humidity (lack of moisture in the atmosphere) by itself seldom causes damage, but when it is accompanied by high temperatures and high wind velocity, plants may show symptoms of excessive water loss from leaves. Fruit may shrivel and plants may wilt, if only temporarily. House plants are often subjected to relative humidities of 15 to 25%, which can be injurious to some plant species since this is equivalent to growing under dry, desert-like conditions.

The most important effect of moisture on infectious disease development seems to be its influence on the survival and germination of fungal spores and their penetration into the host. Some important soilborne pathogenic fungus-like organisms (e.g., *Pythium* and *Phytophthora* spp.) that attack underground parts of plants (roots, tubers, young seedlings) cause their most severe symptoms in soil near saturation. Moisture is also required by many foliar fungal and bacterial pathogens and by nematode parasites. Unlike most fungi, powdery mildews can survive at lower relative humidities that would inhibit other pathogens and are common in dry areas.

Extremes in temperature

At different stages of their growth and development, plants differ in their ability to withstand extremes in temperature. In general, though, extremely low temperatures cause far greater damage to crops than do extremely high temperatures. Temperatures below freezing can kill buds of fruit trees and damage the fruit and succulent twigs of most trees. Low winter temperatures may kill young roots of trees and herbaceous plants or cause bark splitting and canker development. The degree of chilling and frost injuries depends on the duration of the cold temperatures and the degree of temperature drop. (For techniques for protecting trees from frost injury, see chapters 16, “Temperate Tree Fruit and Nut Crops”; 17, “Citrus”; and 18, “Avocados.”) Low temperatures can also adversely affect house plants.

High soil temperatures can damage succulent seedlings and can lead to the formation of lesions or cankers at the crowns of older plants. High air temperatures in conjunction with drought or excessive sunlight may cause bud drop, wilting, leaf scorch, leaf tip burn, and sunscald injuries, particularly on the exposed sides of fleshy fruits and vegetables, such as peppers, apples, strawberries, tomatoes, onion bulbs, and potato tubers. On hot, sunny days, the temperature of tissues beneath the skin on the exposed side of fruits and vegetables may be much higher than the temperature of the tissues on the shaded side and also of the prevailing air. Fruits and vegetables may become discolored, develop a water-soaked appearance, blister, and desiccate beneath the skin, leading to sunken and bleached areas on the fruit surface. Fleshy-leaved house plants placed near windows with a southern exposure may develop symptoms of sunscald in the spring or summer if the sun on hot days is allowed to heat the leaves to an excessive temperature.

Extremes in temperature can also influence the development or progression of infectious plant disease. The most rapid development of infectious disease (the shortest time required for the completion of a disease cycle) occurs when the temperature is optimal for pathogen development and near the optimum for host development. The shorter the disease cycle, the greater the number of new infections that can occur during the growing season.

Wind

Wind is an important factor in the spread of pathogen propagules that cause infectious disease. Insect vectors that transmit plant pathogens are often carried long distances by wind currents. In contrast, wind may also deter infectious diseases by

drying out plant surfaces before penetration can occur.

Light intensity and duration

Inadequate light can slow formation of chlorophyll and lead to leaves becoming pale green and plants becoming leggy, or etiolated (spindly growth with long internodes). High light intensity combined with high temperature can lead to sunscald and other noninfectious disease symptoms, as noted previously. In house plant culture, improper lighting (usually inadequate light) can be a significant problem. Insufficient-light stress can increase plant susceptibility to infection in the presence of a pathogen.

Nutritional deficiencies and mineral excesses

For normal growth and development, plants need the following 17 essential nutrient elements: carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, iron, copper, manganese, zinc, chlorine, molybdenum, nickel, and boron. Mineral excesses and deficiencies have profound effects on plant development, inducing plant disorders and diseases and causing symptoms on leaves, stems, roots, flowers, fruit, and seed.

Inadequate amounts of most essential elements usually reduce growth and yield. Deficiency symptoms, such as yellowing, leaf marginal necrosis (death), leaf scorch, interveinal yellowing (chlorosis), discoloration, distortion, and stunting are common. Many plant diseases occur because of reduced amounts or reduced availability of one or more essential elements in the soil. Low levels of nitrogen in the soil may cause plants to be stunted and chlorotic. An excessive amount of lime in the soil increases soil alkalinity (pH), which binds iron, rendering it unavailable to plants and leading to iron deficiency, a condition known as lime-induced iron chlorosis.

Soil also can contain excessive amounts of essential elements that can cause injury, increase plant susceptibility to disease, or cause toxicity symptoms in plants. Excessive sodium induces calcium deficiency, causes alkali injury, and results in symptoms that may range from chlorosis, stunting, leaf burn, and wilting to death of seedlings and young plants. Excessive boron in irrigation water can kill certain vegetables and trees. These types of damage can occur if the soil and irrigation water are high in salts or if the plants were overfertilized.

Air pollution

Common air pollutants in California are ozone, PAN (peroxyacetyl nitrate), nitrogen oxides associated with automobile exhaust, sulfur dioxide, suspended particles (particulate matter), and fluorides (table 6.2). The primary components of smog are ozone (O_3) and PAN. Ozone is formed in the presence of sunlight when oxygen (O_2) reacts with nitrogen oxides that derive from incompletely combusted hydrocarbons from automobile exhaust. The ozone further reacts with nitric oxide (NO) and unburned hydrocarbon radicals to yield PAN and additional ozone, which contributes to buildup of the ozone concentration. Smog has a number of negative effects on human beings (scratchy throats, burning eyes, reduced visibility, respiratory problems), but it can also induce disease symptoms in plants.

Ozone causes more plant damage than any other air pollutant. The disease symptoms caused by air pollutants—chlorosis, leaf necrosis, white spots or bleached areas on leaves, defoliation, silvery bands or bronzing on lower leaf surfaces—are difficult to distinguish from symptoms caused by certain nutrient deficiencies, pathogens, or insects. Making a correct diagnosis often requires a well-trained specialist. When plants are exposed to mixtures of air pollutants and a range of pathogens (fungi, bacteria, viruses), insect pests, and adverse environmental factors all at once, diagnosis becomes more difficult.

A plant's stage of development influences its response to air pollutants. Some

plants are sensitive when young and insensitive at maturity. Certain varieties of common garden plants (e.g., tomato, onion, corn) are more sensitive to air pollution than others (e.g., beans, citrus, grapes). Many air pollutants enter plants through stomata, the tiny pores concentrated primarily on the lower surface of leaves. When air pollutants penetrate the leaves of a susceptible plant via the stomata, they can decrease the rate of plant metabolism and can damage the chlorophyll molecules responsible for the green color of leaves. Destruction of chlorophyll causes leaves to become chlorotic (yellowed). Pollutants may weaken plants and predispose them to infectious diseases or insect infestation.

Air pollutants produce their negative effects in minute quantities measured in parts per million (ppm) or parts per billion (ppb), as noted in table 6.2. The median toxic dose refers to the amount of pollutant that results in 50% of the plants showing injury and damage. Both the concentration of the pollutant, in ppm or ppb, and the exposure time determine the dose. Federal and state guidelines have established air-quality standards to protect human beings and vegetation from injurious doses of air pollutants.

Identifying and Diagnosing Diseases

Identifying and diagnosing plant problems are essential for developing effective control strategies, which are discussed briefly in this chapter and in chapter 9, "Safe and Sustainable Pest Management," while diagnosing plant problems is discussed in more detail in chapter 21. When disease occurs, the causal agent or factor must be identified first, then effective management strategies can be implemented.

Table 6.2.

AIR POLLUTION INJURY TO PLANTS

Pollutant	Source	Selected susceptible plants	Disease symptoms	Comments
ozone (O_3)	automobile exhaust	expanding leaves of all plants, particularly bean, citrus, petunia, pine, corn, grape, alfalfa	stippling, mottling, and chlorosis on leaves, primarily on upper leaf surfaces; spots are small to large and bleached white to tan, brown, or black; premature defoliation and stunting may occur in citrus, grapes	most destructive air pollutant to plants; major smog component; enters via stomata
peroxyacetyl nitrates (PAN)	automobile exhaust	many kinds of plants: spinach, petunia, tomato, lettuce	causes silver leaf, bleached white to bronze spots on lower leaf surfaces that may spread throughout leaf and resemble ozone injury	can be severe in metro areas with smog and inversion layers
sulfur dioxide (SO_2)	automobile exhaust, factories	many kinds of plants: violet, conifers, pea, cotton, bean	general chlorosis (low concentration); bleaching of interveinal leaf tissues (high concentration)	toxic at 0.3–0.5 ppm; may form acid rain if combines with moisture
nitrogen dioxide (NO_2)	combustion	many kinds of plants: bean, tomato	bleaching and bronzing similar to SO_2; may also suppress growth	toxic at 2–3 ppm
particulate matter (PM) (dusts)	dust from factories	all plants	dust layer on plant surfaces; plants become chlorotic, grow poorly	measured as PM-10 (particles < 10 microns); Riverside and San Bernardino Counties have worst PM-10 levels in U.S.
hydrogen fluoride (HF)	oil refineries	many kinds of plants: corn, peach, tulip	leaf margins of dicots and leaf tips of monocots turn brown and die	toxic at 0.1–0.2 ppb

Source: Adapted from Agrios 2005, p. 369.

Diagnosis of the cause is not an easy task, because many symptoms associated with pathogens, environmental factors and stresses, insects and other pests, or gardening or production problems resemble each other. Also, most plant pathogens are microscopic. When pathogens are detected on the surfaces of a host plant or inside the vascular tissues of a host plant, particularly at the margins of diseased tissue, or when they are detected on or in roots, the pathogens are probably the cause of the disease symptoms. When fungi and bacteria are detected, determine whether pathogenic, rather than saprophytic, species have been identified before pronouncing the fungi or bacteria as the causal agents. Detection and identification require careful observation, a hand lens with magnification of 8× to 10×, a notebook for keeping records, small vials and plastic bags for collecting samples, and, depending on the pathogen's size, professional examination (with a compound, phase-contrast, or electron microscope), and lab tests. Plant pathologists are designing more sophisticated nutrient media for growing pathogens in pure culture in the laboratory to aid in identification and diagnosis. Plant pathologists are also developing and refining diagnostic tests using serological and molecular techniques (such as DNA fingerprinting).

The following list indicates the primary information needed to diagnose disease problems. The list is not comprehensive. Additional detailed questions are usually necessary for each specific situation. Unfortunately, by the time disease symptoms occur, it may be too late to eradicate the problem during the current growing season, but the following kinds of information will be useful for preventing and managing disease in subsequent growing seasons:

- types of disease symptoms present: damping-off, root galls, internal discoloration, wilt, blight, shot holes, yellowing, leaf curling, defoliation, mosaic, leaf spots, stunting, and so on
- host plant, including species, cultivar or variety, and source of stock; its developmental stage; and information regarding any genetic resistance that the cultivar or variety may have
- site history: common disease problems known to occur in the area (e.g., cucurbits and powdery mildew, pears and fire blight) and records that indicate certain diseases have occurred at the site in previous seasons
- time of the year
- pattern of symptoms (in rows, scattered, etc.)
- cultural practices (irrigation, fertilizers and pesticides used, pruning methods, raised beds)
- environmental conditions: air quality, prevailing temperatures, soil quality, light, recent weather patterns (rains, hailstorms, elevated temperatures, etc.)
- pathogen signs, especially the presence of resting structures, fruiting bodies, mycelia, spores, bacterial ooze, and possible nematode cysts
- laboratory tests: isolation, identification, and verification of pathogenicity

In general, it is much more difficult to diagnose the causes of disease symptoms than it is to diagnose the causes of insect pest symptoms because disease symptoms tend to be more variable. When comparing symptoms in the backyard with the color photographs and descriptions in the University of California Integrated Pest Management materials referenced in this chapter or other resource books, examine several affected plants at several stages of ill health. Look for plants with different stages of disease symptoms because the information will help determine the progression of disease. Do not rely on a single symptom for diagnosis; examine as many parts of the diseased plant as possible. Pull plants up to check roots, because many aboveground symptoms are caused by pathogens and stresses that attack roots.

Try to also examine a healthy specimen for comparison with the affected plant.

Principles of Plant Disease Management

The disease development process must be understood in order to devise effective management strategies. Most effective disease control measures are primarily preventive in nature and should begin before pathogens penetrate and infect plants and before symptoms are observed. Almost all control techniques focus on protecting plants from becoming diseased rather than on curing them once disease has occurred. By the time disease symptoms are expressed, the pathogen (with few exceptions) is already inside the host plant in a relatively protected environment, and it may be too late to reverse the damage. In some cases, after disease symptoms occur, no effective management strategy exists other than removal of the diseased plants.

Correct diagnosis of the current problem allows for planning a control strategy to prevent the disease during the next growing season, and measures can be taken to make the garden inhospitable to pathogens, which will help limit the need for pesticide applications.

When possible and practical, take action to prevent disease problems before they occur by choosing resistant varieties, providing optimal conditions for plant growth, and taking preventive action against pathogens known to be a problem in the area. As much as possible, choose a planting site that does not have a history of soilborne or other disease problems. Purchase seeds and vegetative propagating material from reputable suppliers, and when appropriate, purchase certified disease-free seeds, scions, rootstocks, and vegetative propagules. Once the home garden and home landscape are planted, inspect plants at least once a week (twice a week at the peak of the growing season or more often if it appears that a problem may be developing) for disease symptoms, pathogen signs, and other evidence of pest infestation. Rogue out diseased plants.

When you do find diseased plants, try to identify the causal agent, or at least rule out certain possibilities, using the information and principles learned in this chapter. When checking trees, check a few leaves on each side of the tree as well as the trunk. Examine fruit on the tree and those that have fallen to the ground. Cut fruit open and inspect. If plants appear wilted, carefully dig up a few and observe the roots to check for signs of nematodes, vascular pathogens, or root-infesting insects. If a pathogen or insect does not seem to be associated with the symptoms, try to determine whether one of the abiotic noninfectious disease factors highlighted in this chapter may be the cause. As part of this process, evaluate fertilization and irrigation regimes, soil and water quality, drainage, and the prevailing weather. Keep notes of your observations, the date, time of day, stage of crop development, any intervention that you took, and the results.

Disease control strategies will most likely fail when the causal agent is not identified properly, since the control action will probably not be effective against the offending organism or cause that was misidentified at the outset. Some problems may require professional diagnosis. The county agricultural commissioner's office and the UC Cooperative Extension farm advisor may be able to help identify a pest problem or direct you to professional diagnostic services.

The basic principles of an integrated disease control program include

- pathogen exclusion
- site selection to avoid pathogens
- pathogen eradication or plant protection through pesticides and other treatments
- crop rotation and planting of nonhosts

- use of resistant plant varieties
- sanitation and avoidance of contaminating inoculum
- appropriate cultural practices
- weed and vector management

Usually, maximum success in controlling plant disease occurs when a combination of management methods is employed. These principles are discussed in greater depth in this section.

The majority of regulatory control measures focus on pathogen exclusion from certain host plants or a geographic area. Biological control measures focus on techniques that favor microorganisms antagonistic to the pathogen. Chemical and physical control measures focus on protecting host plants from pathogen inoculum and on minimizing an infection in progress. The majority of cultural control measures focus on pathogen reduction and eradication and on techniques to protect plants from contact with pathogen inoculum.

Familiarity with crops, their diseases, and the insect vectors associated with them is useful in planning control programs. Some diseases occur every season; others occur sporadically. Some can be easily controlled using proper methods; others are more challenging. Except for fruit and landscape trees or other high-value plants, the loss of one or a few plants in home garden plantings may be considered unimportant; control measures focus on saving the population rather than a few individuals. Knowing the proper control method to use at the proper time requires integrating the strategies described below. Usually, success in controlling plant disease occurs when a combination of management methods is used.

Pathogen Exclusion

Exclusion strategies attempt to prevent the introduction and spread of pathogens into an area. Government-regulated quarantines, inspections, and voluntary or compulsory eradication of certain host plants are common exclusion techniques. As a nation, the United States attempts to exclude certain pathogens by establishing quarantines and by stationing plant inspectors at various points of entry into the country, as discussed in the introduction to this chapter. The Plant Quarantine Act of 1912 prohibits or restricts entry into or passage through the United States of plants, plant materials, soil, and other materials from foreign countries that carry or are likely to carry plant pathogens not known to be established here. The U.S. Animal and Plant Health Inspection Service (APHIS) has quarantine inspectors stationed at entry points into the United States and at certain interstate points to prevent the introduction of foreign plant pathogens into new areas. Quarantine inspectors from the United States also travel abroad to inspect, for example, the flower fields in Holland for diseases because flower bulbs are imported annually. In California, intrastate transport of citrus budwood and trees is regulated to keep pathogens out of certain areas. Intrastate transport of citrus fruit is regulated during outbreaks of the Mediterranean fruit fly.

Backyard gardeners can practice pathogen exclusion by purchasing certified disease-free seed and vegetative propagating materials and by carefully inspecting planting stock and transplants from the nursery for signs and symptoms before transporting them into the yard. Exclusion is also achieved by not using planting mixes, containers, pruning tools, and other items that might be contaminated with pathogens.

Site Selection

Proper site selection creates conditions that favor plant growth and development and inhibit the growth and development of (or avoids the presence of) disease-causing agents. For example, adequate soil drainage is important in minimizing many root diseases, and sites with good air circulation can be less conducive to development

of certain foliar diseases such as powdery mildew. As with crop rotation principles, site selection also includes attention to the cropping history of the site and avoiding sites that have a high probability of disease developing in new plantings. This is especially important to consider where a past crop or planting was infected by an organism that causes soilborne disease and is also known to affect the next crop or planting being considered for the site. In some instances, the relative closeness or proximity of plantings is important, as when establishing new plants immediately next to established plants of the same species that are virus infected. In situations like this, select a planting site far away from the infected plants to reduce the possibility of the virus affecting the new plants.

Pathogen Eradication or Reduction of Pathogen Inoculum

Once a pathogen is present in the environment, one principle of effective disease control is to keep the population density of the pathogen at very low, nondamaging levels. In such situations, effective control may not mean complete eradication of the pathogen. In other cases, pathogen eradication is the goal, and infected host plants must be destroyed. Twice this century, when citrus canker became a problem in Florida, millions of diseased orchard and nursery trees were destroyed, and the disease was brought under control. Not all such programs are as successful. Attempts by coffee-producing countries in South America to eradicate coffee rust have been frustrated by the continual spread of the pathogen. Backyard gardeners can significantly reduce pathogen inoculum by using cultural techniques such as those described below.

Careful sanitation

Keep garden tools clean to avoid spreading contaminated soil or pathogens from infected plants. When working with diseased plants, sterilize equipment with household bleach diluted 1 to 9 with water. Use this weak bleach solution to sterilize pruning shears when removing diseased limbs from trees and other diseased tissue. Wash treated tools before storing them, because bleach is corrosive. If you suspect soil pathogens, clean off your shoes, too. Tires of vehicles and carts can transport pathogen-infested soil and should also be sanitized. Wash your hands thoroughly after handling diseased plants.

Roguing and pruning

Remove diseased plants and plant parts promptly as soon as you observe them. Bag them and discard them. Prune and destroy diseased foliage from trees and shrubs to prevent spread to adjacent healthy tissues.

Crop rotation

Planting a crop that is not a host for a particular pathogen for a period of 3 to 4 years can significantly reduce pathogen populations in the soil. If this type of formal rotation is not feasible, backyard gardeners should at least avoid planting exactly the same crop or crops from the same family year after year in the same part of the garden to prevent inoculum buildup. It is unwise to plant the same crops or even closely related crops (e.g., members of the potato family or the cucurbit family) in the same garden location every year.

Elimination of weeds and other alternate hosts

Weeds can serve as alternate hosts for a number of disease-causing fungi and viruses. Control weeds in the garden and in adjacent areas.

Repel insect vectors

Reflective mulches of aluminum or whitish gray polyethylene sheets along the edges of crops susceptible to viral diseases vectored by aphids seem to provide some protection by repelling aphids and reducing the inoculum load.

Soil solarization

In the warmer areas of California, a number of soilborne pathogens and pests can

be killed or their populations reduced significantly by covering moist soil with clear plastic (1–2 mil thick) for 2 months (4–6 weeks) in midsummer. The soil will heat up to temperatures that are lethal to many pathogenic fungi, nematodes, weeds, weed seeds, and other pest organisms.

Plant Protection

Crop protection involves disease avoidance techniques and the use of pesticides, organic and synthetic chemicals that kill or control pests. Pesticides that kill or control fungi are known as fungicides; those that kill or control bacteria are known as bactericides; and those that kill or control nematodes are known as nematicides. No viricides have been developed to date. Fungicides and bactericides are available for home garden use. Careful timing is required for these materials to be effective, and repeated applications may be needed to protect new plant growth if conditions favor disease development. Because of the toxic nature of many pesticides, you must devote special attention to their proper use. For detailed information on pesticide labeling, types of pesticides, modes of action, application methods, formulations, additives, legal requirements, prevention of pesticide poisoning, protective equipment and clothing, application equipment, calibration of sprayers and spray patterns, storage and disposal, and environmental concerns, see chapter 9. For additional information about pesticides and their relative effectiveness, refer to *Pests of the Garden and Small Farm* (Flint 1998) and *Pests of Landscape Trees and Shrubs* (Dreistadt 2004).

Many naturally occurring organisms kill or retard the growth of plant pathogens. However, little is known on how to manage most of these beneficial organisms, so there are no general recommendations on using them effectively. A few beneficial organisms or their by-products are commercially available for use in preventing diseases, but these products have not been consistently effective. Details of these are discussed in *Natural Enemies Handbook* (Flint and Dreistadt 1998) and *Pests of Landscape Trees and Shrubs*.

According to *Pests of the Garden and Small Farm*, "the diligent backyard gardener who is willing to sacrifice a few plants to disease should be able to get by with very little use of pesticides for the control of pathogens if he or she follows a careful cultural management program" (Flint 1998, p. 139). Following an integrated disease control program outlined earlier will also enable gardeners to minimize the use of any pesticides. Flint does note two exceptions: peach leaf curl on peaches and nectarines and powdery mildew on grapes. Similarly, *Pests of Landscape Trees and Shrubs* notes that "with careful cultural management, at least some cultivars of most landscape plants can be grown at a high level of aesthetic quality with little or no pesticide application" (Dreistadt 2004, p. 218).

Backyard gardeners can protect plants and avoid diseases by using a number of practical techniques:

- Plant at a time of year that does not favor the pathogen.
- Select a planting site that provides adequate sunlight and good drainage. Powdery mildew and molds are more serious problems in shady areas; root diseases, particularly those caused by parasitic nematodes and damping-off fungi, are more of a problem in soil with poor drainage.
- Choose plants that have a history of success in the particular microclimate and use resistant varieties when available.
- Provide adequate plant spacing. Crowding favors damping-off fungi and Botrytis gray mold on vegetables. Make conditions unfavorable for pathogens.
- Use adequate fertilization and irrigation to promote plant health. Do not overwater, as excess water favors root pathogens. Water early in the day so foliage can dry out quickly, because many fungal and bacterial pathogens

need free moisture or high relative humidity to begin attacking host tissue. Maintain an even water supply during the growing season.

Group plants according to their water and sunlight requirements. Do not plant a crop that needs frequent, light watering next to one that needs infrequent, deep watering.

Handle plants and plant parts carefully during harvest and storage.

Avoid injuries and wounds when handling, harvesting, or caring for plants. Such practices allow a plant's natural protective mechanisms to remain intact.

Use disease-free planting stock, sanitary cultural practices, and crop rotation, as appropriate.

Use of Resistant Plant Varieties

Disease-resistant varieties provide the best, most reliable, and most economical method of controlling diseases caused by certain viruses, fungi, and nematodes. A number of crop plant varieties on the market today are resistant to some rusts, smuts, powdery mildews, vascular wilts, viruses, bacteria, and parasitic nematodes. A number of rootstocks for fruit and nut trees resist attack by common pathogens. Some resistant crop varieties inhibit pathogen attack because of their synthesis of toxic or repellent compounds; others resist pathogens through physical factors, such as thick cuticles; and still others are tolerant, which means that they resist pathogens and disease by suffering little or no damage after pathogen attack. Proper culture of a crop can enhance host resistance and tolerance and prolong the lifetime of a resistant or tolerant variety after its release.

Resistance is not the same as immunity. A resistant crop can endure attack by a particular pathogen; an immune crop would not be attacked by the pathogen even under the most favorable conditions. Check with the nursery or seed supplier to see if resistant varieties are available and which ones are best suited to local conditions and needs. Keep in mind that improper culture of a resistant variety may negate resistance traits.

Integrated Pest Management

The University of California encourages gardeners to manage disease-causing pathogens and other pests using an integrated pest management (IPM) strategy. A central concept in IPM is that of integrating several control methods, such as resistant varieties, cultural practices, biological controls, and the least-toxic pesticides for long-term management of pests. An IPM approach encourages methods that provide long-term prevention or suppression of pest problems with minimum impact on human health, the environment, and nontarget organisms.

A fundamental concept of IPM is that a certain amount of disease (or pest damage) can be tolerated. Broad-spectrum pesticides are used only as a last resort when careful monitoring and preestablished guidelines indicate that they are needed. An IPM program can be carried out in most garden situations with almost no use of pesticides that are more toxic than fungicidal and insecticidal soaps, horticultural oils, or microbials. Backyard gardeners must be willing to sacrifice a few vegetable plants, for example, and tolerate a little cosmetic damage so that the use of pesticides can be minimized. Backyard produce does not need to meet industry or marketplace standards. See chapter 9, "Safe and Sustainable Pest Management," for further information on IPM.

Applying General Disease Management Principles to Control Infectious Disease

This discussion briefly applies the general principles of managing infectious disease. For more information on identification and practical control measures for infectious diseases, as well as insect pests, weeds, and abiotic agents, see *Pests of the Garden and Small Farm*, *Pests of Landscape Trees and Shrubs*, *Abiotic Disorders of Landscape Plants*, and the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden.

Management of Diseases Caused by Fungi

A number of effective organic and synthetic fungicides are available for managing plant-pathogenic fungi. Most fungicides are applied to the foliage as sprays or dusts to control or prevent diseases on the aboveground parts of susceptible hosts. Because many fungicides protect host plants from infection by a pathogen, they must be applied before a pathogen infects the plant. Fungicides should be reapplied throughout the growing season to protect newly developed foliage that was not covered during previous applications and to replace fungicide that has degraded on the plant. The timing of fungicide application is critical for success. It is often too late to spray once disease symptoms are noticed. Diagnosing the presence of a fungal disease in one season enables management plans to be developed for control the next season, but the severity of some fungal diseases fluctuate with the prevailing weather conditions, which may be different during the next growing cycle. Determine whether a foliar fungicide or a soil fungicide would be more effective in the particular disease situation in question. Apply the fungicide properly, cover the plant thoroughly, and use rates recommended on the label, following all label directions and precautions.

Plant breeders have developed varieties of crop plants that have the genetic makeup to resist major classes of fungal pathogens, such as powdery mildew and vascular wilts, under typical prevailing environmental conditions. Select and plant resistant varieties in your backyard whenever possible. Use pathogen-free seeds or propagating stock.

Cultural practices such as destruction of plant parts or debris harboring the pathogen and use of clean tools and containers lessen the inoculum load. The risk of fungal disease can be further reduced with proper soil drainage and aeration, appropriate irrigation practices, and other cultural practices that minimize plant stress. Crop rotation can help control diseases caused by some fungi but not for those having a wide host range or those that can survive for long periods as resting structures in the soil.

Management of Diseases Caused by Bacteria

Effective strategies for controlling bacterial diseases rely on a combination of management techniques: planting resistant host varieties, when available; practicing sanitation by removing infected debris and using clean tools; employing cultural practices that do not favor bacteria, such as avoiding sprinkler irrigation, planting in well-drained areas, and not crowding plants; and using certified disease-free seed. At the nursery, rejecting roses or fruit trees with suspicious bumps may limit the spread of the bacterial pathogen that causes crown gall. Few bactericides are available for home garden use.

Management of Diseases Caused by Viruses

Viruses can be difficult to manage; thus, it is most effective to keep viruses out of an area via quarantine, inspection, and certification programs, such as those for citrus in California. For information about the certified disease-free citrus budwood pro-

gram at the University of California, see chapter 17, "Citrus."

No chemical viricides have been developed for controlling viral diseases in the field, so practices that exclude or remove virus pathogens are commonly followed to limit virus spread, including the use of virus-free propagating materials, disposing of infected plants, controlling insects and other vectors to the extent possible, and using disinfested, clean tools. Plant breeders have developed varieties of some crops that are resistant to certain viruses.

Some viruses invade apical meristems, but other viruses do not invade the growing points of stems or roots of infected plants. If the apices of roots and stems remain virus-free, scientists who specialize in tissue culture techniques can use the virus-free apical meristems to culture virus-free clones of specific plants in the laboratory, even though the majority of the tissues of the specific plant in question are infected by the virus.

Management of Diseases Caused by Nematodes

Management of nematodes is achieved through cultural practices such as sanitation and crop rotation to nonhost plants, planting resistant varieties, soil sterilization with heat, and soil fumigation with nematicides, chemicals designed to kill or control nematodes. Backyard gardeners cannot control nematode diseases with chemicals because no nematicides are registered for use by homeowners. In the garden, interplanting with marigolds is said to provide some measure of control because they are toxic to nematodes, but the scientific evidence for interplanting is questionable. Asparagus plants produce a chemical toxic to many nematode species.

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UC IPM Pest notes. Updated regularly. UC IPM website, http://www.ipm.ucdavis.edu/homegarden.

Insects 7

Richard H. Molinar

Learning Objectives

Learn about insect structure (anatomy), life cycles, and distribution.

Become familiar with the major groups of insects found in the home, landscape, and garden.

Learn basic information about diagnosing plant problems caused by insects and mites.

Learn about the methods and principles for managing insect pests.

This chapter is intended to be used in conjunction with chapter 9, "*Safe and Sustainable Pest Management*," in this book, along with *Pests of the Garden and Small Farm* (Flint 1998b), *Pests of Landscape Trees and Shrubs* (Dreistadt 2004) and the UC IPM Pest Notes, ipm.ucdavis.edu.

Insects

Insects occupy virtually all habitats on earth except the open ocean. Insects live in or on animals, plants, soil, wood structures and furniture, streams, lakes, ocean shores, and stored grain and other foods.

Insects are the most abundant animals on this planet. About one million different kinds, or species, of insects are known to exist, and the final count may be far greater. The total number of species may never be determined because scientists who classify insects continually combine several species into one or separate insects previously considered a single species into two or more species; also, some species are yet to be identified, and certain others are becoming extinct before we can identify them.

By no means should all insects be considered destructive. The vast majority are neutral or have a beneficial effect. For example, bees and many other insects serve as pollinators in many crops. Killing bees with the indiscriminate use of insecticides reduces fruit set in crops that are pollinated by bees. Other beneficial insects prey on or parasitize pest insects, using them as a source of food and helping to keep pest populations under control.

Pest insects cause serious economic damage by destroying food crops in the field and in storage. It is estimated that one-sixth of the world's food crops are consumed by insect pests. They also carry viral, bacterial, and fungal diseases, which they transmit to crop plants, livestock, and humans.

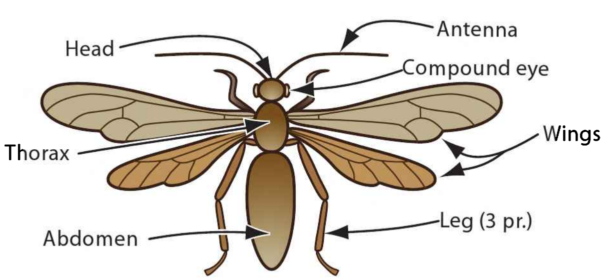
Insects and Insect Relatives

Insects belong to the group of animals known as Arthropods ("jointed legs"), which includes crabs, lobsters, spiders, and ticks. Arthropods have an exterior skeleton, known as an exoskeleton, which provides support but differs from the internal skeleton of mammals. Scientists who study insects are known as entomologists. To be classified as an insect, the adult form, which is highly variable, must have the features listed below (fig. 7.1):

- Three distinct body regions. Insects have a distinct head, thorax, and abdomen. The thorax supports the legs and wings.
- Jointed legs (three pairs). An insect's six legs are attached to the thorax (one pair per thorax segment) and can be specialized for jumping, grasping, or walking.
- Antennae (one pair). The antennae, attached to the head, are sensory organs. The antennae can be short, long, smooth, serrated, or feathery.

Figure 7.1

The body parts of an insect. *Source:* After Barker et al. 1991, p. 1.



Wings (none, one, or two pairs). Although most adult insects have the ability to fly, some do not have wings. Wings are attached to the thorax and vary from very ornamental and colorful to clear. The vein pattern on the wings of insects is important for identification of species.

Unlike humans, insects are cold blooded; the ambient temperature of the environment in which they live determines their body temperature. The majority of insects are most active during warmer months and during the warmer part of the day. Their development rate is also based on temperature, so they pass through stages from egg to adult more quickly in the warmer months.

A number of other pests that are not insects are often wrongly called insects. These insect relatives include pillbugs (crustaceans), centipedes (chilopods), millipedes (diplopods), snails and slugs (mollusks), and spiders, ticks, and mites (arachnids). The following section gives a brief overview of common insect relatives in the home and garden.

Common Insect Relatives in the Home and Garden

Arachnids: Mites and Spiders

Arachnids have no antennae, no wings, and two body regions, the cephalothorax and abdomen. Adult arachnids have four pairs of jointed legs.

Mites (fig. 7.2) are smaller than a period on this page, and a good hand lens is necessary to see most of them. They are common pests of many fruit and nut trees, vegetable crops, ornamentals, and house plants. They feed on plants by inserting their piercing mouthparts into the host and sucking up the liquid cell contents. Mite damage manifests as yellowish stippling (tiny light-colored areas) at the feeding site, general decline, leaf drop, and distortion of leaves, fruit, or blossoms.

Two families, the tetranychids and eriophyiids, cause the majority of mite damage in California. The tetranychid family includes webspinning spider mites, red mites, and brown mites. The webspinning spider mites are the most common mite pests and are among the most ubiquitous of all pests in the garden, according to *Pests of the Garden and Small Farm*. Common species of webspinning mites are the twospotted spider mite, strawberry spider mite, and Pacific spider mite. Web-spinning spider mites live in colonies, primarily on lower leaf surfaces. In favorable environmental conditions (hot and dusty), it takes 1 week for a mite to mature from egg to adult and complete a generation. Because a number of predatory mites and various insects are natural enemies of webspinning spider mites, application of insecticides that kill pest and beneficial insects may lead to increased mite infestation. In the garden, regular, forceful spraying of plants with water, with good coverage on the underside of leaves, often reduces spider mite infestation to a manageable level. Examples of red mites are the citrus red mite and the European red mite. The eriophyid mite family includes the rust, bud, and blister mites, which have four legs rather than the eight characteristic of other arachnids. Examples include the tomato russet and fuchsia gall mites. The feeding of these mites on fuchsia causes leaves, flowers, or fruit to deform or creates galls around the mites.

Spiders are larger than mites and their two body regions are distinct. Most spiders are harmless to humans and are beneficial predators that feed on insects and other small animals by paralyzing their prey with venom. Some spiders do not form webs; instead they lie in wait for their prey. Two

Figure 7.2

Spider mite.

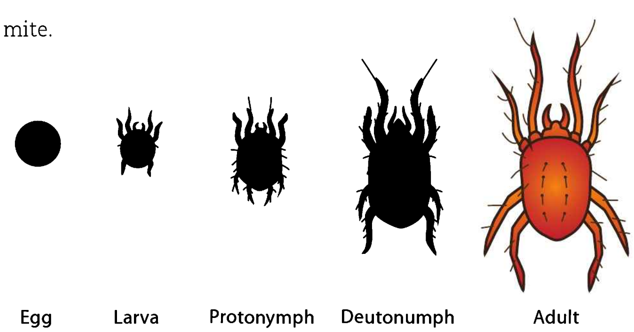


Figure 7.3

Black widow spider.
Photo: J. K. Clark

Figure 7.4

House spider.
Photo: J. K. Clark

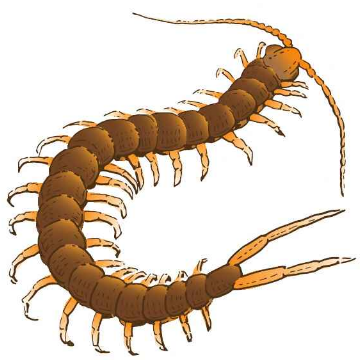
species of spiders that are poisonous are the black widow spider (fig. 7.3) and the brown recluse spider (but this species does not occur in most parts of California). The black widow spider lives in damp, dark places and spins a messy web. It is shiny black, with a reddish or orange hourglass marking on the underside of the abdomen. Brown recluse spiders are found primarily in the southeastern United States and have a violin shape on the upper part of their thorax. The common house spider (fig. 7.4) is frequently found indoors, where it makes cobwebs in corners of rooms. It is not venomous. (See Vetter 2014 for a useful video on spider identification.)

Chilopods: Centipedes

Centipedes (fig. 7.5) are insect predators that resemble millipedes, but their bodies are more flattened. They have one pair of legs on most body segments and long antennae. Centipedes are common in soil, debris, under bark, and in rotting wood. Larger centipedes can bite humans with their large pincer-like appendages and inject venom similar to a bee sting.

Figure 7.5

Centipede.



Crustaceans: Sowbugs and Pillbugs (Isopods)

Sowbugs are soil-dwelling, oval-shaped crustaceans related to crayfish. They breathe through gills and have a hard, outer multisegmented shell. Sowbugs that roll up into a ball when disturbed are called pillbugs (fig. 7.6). Sowbugs have seven pairs of legs and are active at night. They feed on decaying plant material and are therefore important in decomposing organic matter in the garden. Occasionally, they feed on seedlings, new roots, leaves, fruits (strawberries), or vegetables (squash) lying directly on the soil. Sowbugs are blamed for causing more problems than they do because they are frequently associated with decaying plant material that was initially damaged by other pests, such as snails or slugs. Sowbugs are favored by sprinkler irrigation and organic mulch. Black plastic mulch discourages sowbugs

Figure 7.6

Pillbug.

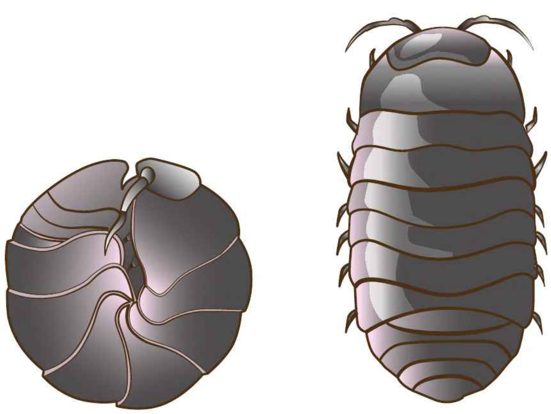


Figure 7.7

Millipede.

Figure 7.8

Brown garden snail.

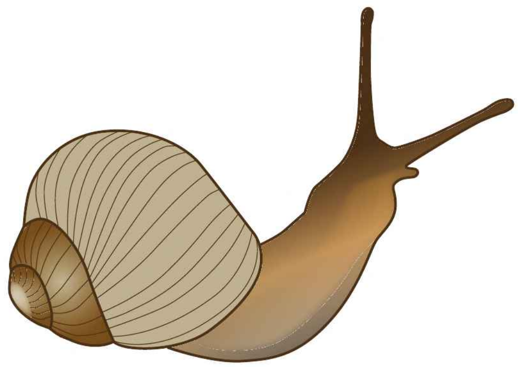
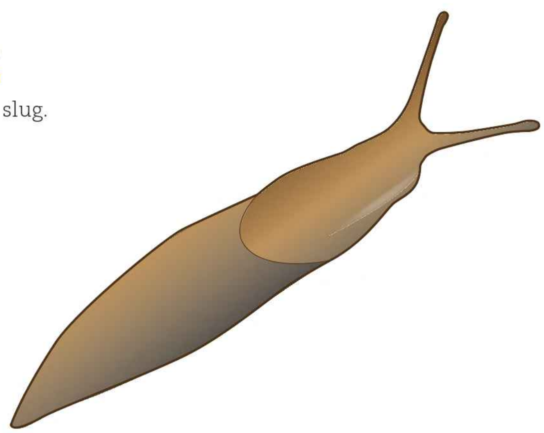


Figure 7.9

Gray garden slug.



because it gets too hot. Limiting the moist, organic decaying matter in the garden reduces the sowbug population.

Diplopods: Millipedes

Millipedes (fig. 7.7) are wormlike, have a visible head, one pair of short antennae, and an elongated, rounded body. They have two pairs of legs on most body segments. They are often found in soil and feed on fungi and decaying organic matter. They are harmless to mammals.

Mollusks: Snails and Slugs

The brown garden snail *(Cornu aspersum)* (fig. 7.8), the gray garden slug *(Deroceras reticulatum)* (fig. 7.9), and others are among the most bothersome pests in California gardens. Slugs lack the snail's external spiral shell. Both pests are most active at night, especially after irrigation, and on foggy or cloudy days. They move by sliding along mucus or slime trails secreted by a single foot. Both feed on decaying organic matter, seedlings, and low-growing leafy vegetables and ripening fruits, such as lettuce, strawberries, and tomatoes. Three tools for managing snail and slug pests are limiting their daytime hiding places such as debris and weedy areas, handpicking them frequently, and collecting them from under boards and flowerpots positioned throughout the garden. Consider using snail-proof plants such as impatiens, geraniums, begonias, lantana, nasturtiums, sage, rosemary, and lavender. Snails collected in a bucket can be crushed or killed using sprays of household ammonia diluted to 5 to 10%.

Insect Growth and Development

Every insect begins life as an egg; however, the eggs of some destructive insects, such as many aphid species, hatch within the body of the female parent, and immatures are born as living, young insects. Insect eggs are often tiny and difficult to spot, but they are often a good indicator of future pest outbreaks. Examples of some of the more distinctive egg shapes are shown in *Pests of the Garden and Small Farm*.

Insects grow by shedding their outer skin (exoskeleton), which is quite rigid. The skin-shedding process, called molting, results in an increase in size and slight to significant modifications in appearance. Immature insects may molt as many as six times. The change in form and appearance from juvenile to adult insect is known as metamorphosis.

There are generally three types of metamorphosis: none, gradual (incomplete), and complete. In some insect species, metamorphosis is called gradual and is relatively indistinct (fig. 7.10). For example, young grasshoppers, crickets, termites, and true bugs look like small versions of their adult counterparts except for the lack of fully formed wings. The immature stages of these insects are known as nymphs.

In other insect species, metamorphosis is marked by four distinct stages, known as complete metamorphosis (fig. 7.11): egg, larva (a feeding, destructive stage), pupa (an inactive stage), and adult (reproductive stage). Bees, ants, wasps, flies, beetles, butterflies, moths, and mosquitoes exhibit complete metamorphosis.

Figure 7.10

Gradual metamorphosis. Insects in this group change gradually. There are three stages of growth, each looking more like an adult. *Source:* After Barker et al. 1991, p. 12.

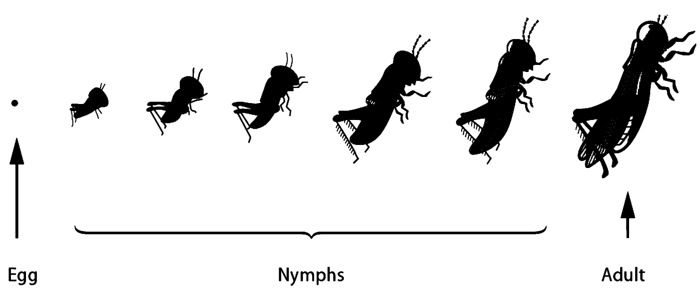
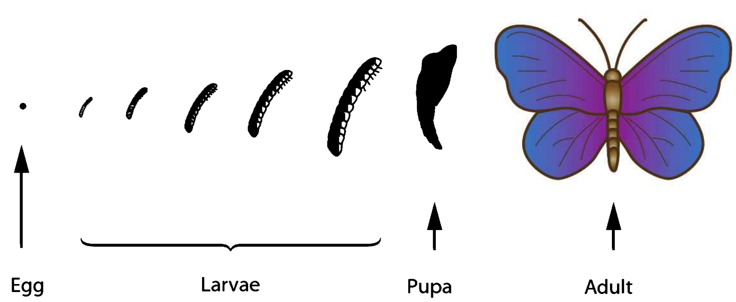


Figure 7.11

Complete metamorphosis. All insects in this group go through four stages of growth. None of the young looks like the adult. There is a great change in shape when the adult emerges from the pupal stage. *Source:* After Barker et al. 1991, p. 12.



The eggs of insects that exhibit complete metamorphosis hatch into larvae that are quite different in appearance from the adult forms. The larval stages of insects that undergo complete metamorphosis typically have different feeding habits from the adult stages. For example, the larvae of butterflies, moths, and flies may damage crop plants, but the adults consume only nectar or do not feed at all. On the other hand, some beetle species, such as cucumber beetles or flea beetles, cause damage as adults but do little harm to crop plants during their larval stages. Molting occurs as insects develop into progressively larger larval stages.

The pupal stage follows the larval stage in insects with complete metamorphosis. Depending on the insect species, pupae may be found inside cocoons, in earthen cells in the ground, or exposed in or on the ground, vegetation, or other places. The adult stage follows the pupal stage. Once the adult form appears, no further molting or increase in size occurs. If an insect has functional wings, it clearly has reached the adult stage.

Mating in adult insects is followed by egg laying by the female and the eventual death of the adults. The females of some insects, such as many aphids and scales, can reproduce in the absence of males, a process known as parthenogenesis.

The life cycle of development from the egg to the production of an egg by the subsequent adult stage is called a generation. Many insect species have only one generation each year, while others have several; the 17-year cicada, however, requires many years to complete a single generation. During a calendar year, a generation need not begin with the egg stage. Many species spend the winter (overwinter) as larvae or pupae; the subsequent adults mate and produce eggs in the spring or summer. In any given area, an insect species normally overwinters in the same stage each year.

Insect Feeding

Insect pests fall into two basic feeding types, chewing and sucking, and each has specialized mouthparts. The larvae of many pest insects have chewing mouthparts. Insect pests that feed by chewing are equipped with strong jaws for that purpose, and their mandibles resemble teeth used for chewing. These larvae and adult insects literally eat their way through the plant, leaving a trail of distinct holes and tunnels in leaves, twigs, fruits, and stems. Chewing damage may be done inside stems and branches or fruit (borers), inside leaves (leafminers), or openly on leaves (defoliators and skeletonizers), flowers, or other plant parts.

Pests that do not have chewing mouthparts have sucking mouthparts. Leafhoppers, aphids, true bugs, scale insects, psyllids, thrips, and whiteflies, among others, pierce plants with a probe-like device, known as a stylet, through which they suck plant sap, depriving the plant's cells of the products of photosynthesis. Sucking insects cause injury symptoms that include curling, stunting, stippling or yellowing, brown mottling, deformed plant parts, and galls. Some piercing insects inject toxic saliva into the plant as they feed, giving rise to discoloration of the foliage or dieback of woody plant parts. Aphids, whiteflies, thrips, and leafhoppers can be vectors of microbial plant pathogens, particularly viruses. If these pest insects have previously fed on diseased plant tissue, they transmit the disease to their next host plant when they insert their stylet into the plant and mix their saliva with plant sap.

In contrast, pests with chewing mouthparts cause more visible loss of plant tissue. Chewing pests may cause holes along the edge or center of the leaf, or they may completely skeletonize the leaf, leaving behind only the leaf veins. Distinguishing the damage as being caused by a chewing or a sucking insect is a first step in identifying a pest.

Larvae and adults with complete metamorphosis sometimes have different types of mouthparts and feed on different foods. Caterpillars (larvae with chewing mouthparts) usually feed on leaves or other vegetation, resulting in a noticeable loss of plant tissue. By contrast, adult moths or butterflies feed on fluids such as nectar because they have a sucking tube that forms siphoning mouthparts.

Insect Breathing and Circulation

Most insects breathe through tiny holes in the body called spiracles. They do not have lungs. The spiracles are located on each side of the insect, about two on the thorax and eight on the abdomen of the adult (two spiracles per segment). Small tubes (tracheae) take the air from the spiracles and move it throughout the body where needed. The process is similar even with aquatic insects that surface periodically to collect a bubble of air. Carbon dioxide is expelled through the spiracles. Whereas humans have a closed circulatory system using blood to carry oxygen throughout the body, insects have an open circulatory system with the hemoglobin-free liquid flowing freely throughout the body cavities. Muscular pumps and body movements force the insect blood out to the extremities. Many insecticides enter the insect pest's body through the spiracles.

Insect Classification and Identification

All known insects are grouped into about 24 categories called orders. Each order contains dozens, hundreds, or even thousands of species. The physical and behavioral similarities among particular species allow scientists to group them. Not all insect orders contain species associated with garden plants. Listed below are examples of insects in selected orders:

Blattodea: cockroaches

Coleoptera: beetles, weevils

Dermaptera: earwigs

Diptera: flies, mosquitoes, gnats, midges

Hemiptera: true bugs, leafhoppers, aphids, scales, whiteflies

Hymenoptera: bees, wasps, ants

Isoptera: termites

Lepidoptera: butterflies, moths

Neuroptera: lacewings, antlions

Odonata: damselflies, dragonflies

Orthoptera: grasshoppers, crickets

Psocoptera: booklice, barklice

Siphonaptera: fleas

Thysanura: silverfish, firebrats

Thysanoptera: thrips

Entomologists use anatomical features (body parts) examined under a microscope to identify, distinguish, and classify insects. Written keys are available to determine the identity of a particular insect. The most important plant-feeding pest insects in the garden are found in the orders Coleoptera, Hemiptera, and Lepidoptera.

The association of insects with plants does not automatically mean that the insects are destructive. Insects in the orders listed below are often found on plants and many are beneficials, functioning as parasites or predators of plant-feeding pest insects, pollinators, or scavengers of dead vegetation or the products left behind by other insects on plants.

Coleoptera: beetles (predators, pollinators)

Diptera: flies (predators, parasitoids, pollinators)

Hymenoptera: bees, wasps (pollinators, parasitoids, predators)

Neuroptera: lacewings, antlions (predators)

Psocoptera: booklice, barklice (scavengers, decomposers)

Insect orders are subdivided into smaller groups known as families, genera, and species. Two examples are listed below:

Codling moth (common name)
Order: Lepidoptera
Family: Tortricidae
Genus: *Cydia*
Species: *pomonella*

Oystershell scale (common name)
Order: Hemiptera
Family: Diaspididae
Genus: *Lepidosaphes*
Species: *ulmi*

The majority of pest insect species, and many others that are not pests, have common names. As noted above, the common name of *Cydia pomonella* is codling moth, and that of *Lepidosaphes ulmi* is oystershell scale. Common names are also often given at higher levels of classification, such as the family and order. The order Lepidoptera refers to the butterflies and moths, and the order Hemiptera, family Diaspididae, refers to armored scales.

Identifying a given insect to the species level is often difficult, and in some cases, it may not be necessary for the home gardener as long as the gardener is careful to distinguish pest insects from nonpests. For example, to be able to offer good advice for controlling most aphids does not require that the exact aphid species in question be determined. The same could be said about most soft scales, mealybugs, spider mites, and many other common garden pests as long as the plant host has been identified.

When attempting to identify a plant-feeding insect, it is of great importance to know the identity of the plant on which the insect was found. Although some insect pests are general feeders (e.g., grasshoppers and earwigs), that is, they feed on a variety of different plants, many are quite host specific. The juniper twig girdler, for example, attacks only juniper and is never found on pine, cypress, oak, camellia, or any other plant. The tomato hornworm occurs only on tomatoes and eggplants, and the California oakworm, for all practical purposes, only on oak. Examples of specific and general pests that may

occur on different garden plants are described in detail and shown in color photographs at various stages of development in *Pests of the Garden and Small Farm* and *Pests of Landscape Trees and Shrubs*. Master gardeners should refer to these two resources to narrow the possibilities in the insect identification process.

Knowing the identity of the host plant and pest is of critical importance when offering advice on chemical pest control, especially when the plant is a vegetable, fruit, or other food-bearing plant. This is discussed in more detail later in this chapter, in the section "Chemical Control."

Common Insects in the Home and Garden

Coleoptera: Beetles and Weevils

Metamorphosis: Complete

Mouthparts: Chewing

Attributes: Larvae (e.g., grubs, wireworms) have head capsules, soft bodies, and short legs grouped near their head but never have leg-like appendages (prolegs) on their abdomen. Adults have two pairs of wings. Horny, leathery front wings meet in a straight line down back and cover membranous hind wings underneath, which are used for flying. There are usually noticeable antennae. Weevils are beetles with snouts.

Beetles are very common (about 40% of all insect species), but most are not garden pests. Many species, such as lady beetles (ladybugs) (fig. 7.12), are beneficial predators of pests such as aphids and mites. Flea beetles, wireworms (click beetle larvae), cucumber beetles (see fig. 7.12), vegetable weevils, and green fruit beetles are common pests in California home vegetable gardens. Boring beetles attack trunks and branches of fruit and nut trees. Granary weevils (see fig. 7.12) attack stored grain and nut products. Adult pest beetles may feed on the same crops as their larvae, unlike other pest groups, such as caterpillars (larvae of butterflies and moths) and maggots (larvae of flies), whose adults do little damage.

Figure 7.12

Lady beetle (left), spotted cucumber beetle (center), and granary weevil (right).

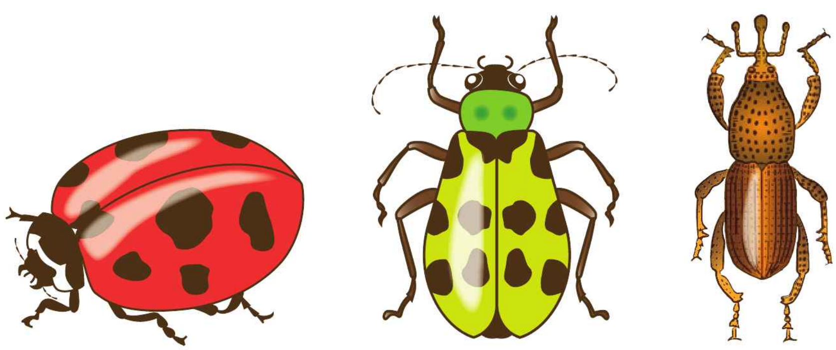
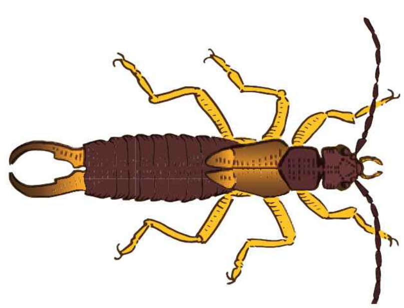


Figure 7.13

Earwig.



Dermaptera: Earwigs

Metamorphosis: Gradual

Mouthparts: Chewing

Attributes: Elongate, flattened insects with strong, movable forceps on rear end. Adults and nymphs resemble each other, but wings are small or absent on nymphs. Two pairs of modified wings consist of a thickened, leathery, short front pair that meet in a straight line down the back and cover the membranous hind wings. Antennae are threadlike, about half of the body length.

Earwigs (fig. 7.13) can be pests or beneficials in the home garden. They are effective predators of aphids in apple orchards, but they are pests in the vegetable garden. Earwigs feed on plant shoots, seedlings, and a variety of dead and living organisms. Earwigs can be trapped in rolled-up newspaper or tuna cans filled with vegetable oil, fish oil, or bacon fat. They are nocturnal and hide during the day in leaf litter and mulch or under bark.

Diptera: Flies, Mosquitoes, Gnats, Midges, Leafminers

Metamorphosis: Complete

Mouthparts: Larvae, chewing or mouth hooks; adults, piercing or sponging

Attributes: Larvae of flies (maggots) have no true legs and are white and wormlike, lacking a head capsule. Adults are soft bodied, have compound eyes, one pair of membranous wings, and are hairy. Mosquito larvae have head capsules.

Adult houseflies (fig. 7.14) can infest homes, poultry houses, or livestock barns. Maggots (larvae) of houseflies are found in manure and decaying matter. Important garden and agricultural pests include the cabbage maggot, which infests roots; seedcorn maggot, which damages seeds and germinating seedlings of many vegetables; and onion maggot, which attacks bulbs of onions, leeks, and garlic. It is almost impossible to distinguish these three species of maggots in the field. Adults resemble the common gray housefly. Diptera are active year-round and produce several generations per year. Other important fly pests are the walnut husk fly, apple maggot, and fruit flies. They lay their eggs in vegetables, fruits, or nuts, and the larval damage renders the produce unmarketable. Most fruit flies, such as the vinegar fly, attack fruit only after it ripens; however, the spotted wing Drosophila infests cherries and berries as they begin to ripen, often causing severe losses.

A number of leafminers are in the fly family as well (other leafminers are in the Lepidoptera). The adult flies deposit their eggs in leaves, and the larvae burrow through the leaf, feeding and creating a mine.

Mosquitoes are also in this family. Adult mosquitoes (see fig. 7.14) are slender, frail flies. Mosquito larvae typically live in water. The adult female mosquito uses her mouthparts to pierce the skin of mammals and birds, then sucks their blood, transmitting diseases such as malaria to humans in the process. Mosquito larvae live in water, so one method of control is to eliminate standing water.

One beneficial group of dipterans are the syrphid fly larvae, which are important predators of aphids. Syrphid larvae look like small green or brown slugs or legless caterpillars and can be observed busily eating aphids. The adult syrphid, or hover or flower fly, is often mistaken for a bee, but it is much quicker and does not buzz.

Figure 7.14

Housefly (left) and mosquito (right).

Hemiptera: True Bugs (suborder Heteroptera) and Aphids, Scales, Whiteflies, Mealybugs, and Leafhoppers (suborder Homoptera)

Metamorphosis: Gradual

Mouthparts: Piercing-sucking

Attributes: Heteroptera, or true bug, nymphs are small versions of adults, except that nymphs lack wings until they are about half-grown. Adults have two pairs of wings. When the wings are folded, their tips overlap to form a well-defined X on the back of the bug body. Some, such as the lygus bug, also have an inverted triangle behind their heads. The inverted triangle and X formation facilitate recognition. Eggs are cylindrical, barrel, or keg shaped. One to several generations occur per year. There is wide variation in the Homoptera group, but many are small, soft-bodied insects. There are winged and unwinged forms. Some are carriers of plant pathogens. Many aphid species have two cornicles (tubelike projections) protruding from the rear end.

Adults and nymphs of many true bug species are important plant-feeding pests

of many fruits and vegetables. Examples are stink bugs (fig. 7.15), lygus bugs, squash bugs, and harlequin bugs. Stink bugs are shield shaped, with a large inverted triangle on their backs. Nymphs of lygus bugs can be confused with aphids, but they move faster than aphids and have red-tipped antennae. Squash bugs feed on vines and fruit of cucurbit crops; control squash bugs by handpicking adults and brown egg masses from leaves. True bug pests suck out contents of plant cells, damaging and distorting leaves, buds, and fruits. Species that inject toxins while feeding cause yellow spots on leaves and ripening fruit. Symptoms may not appear until long after the bugs have left, making diagnosis difficult. Some true bugs (e.g., assassin bugs, damsel bugs, minute pirate bugs, and certain stink bugs) are predators of pests and function as important beneficials in the garden, feeding on a variety of pest insects.

Figure 7.15

Stink bug (left) and harlequin bug (right).

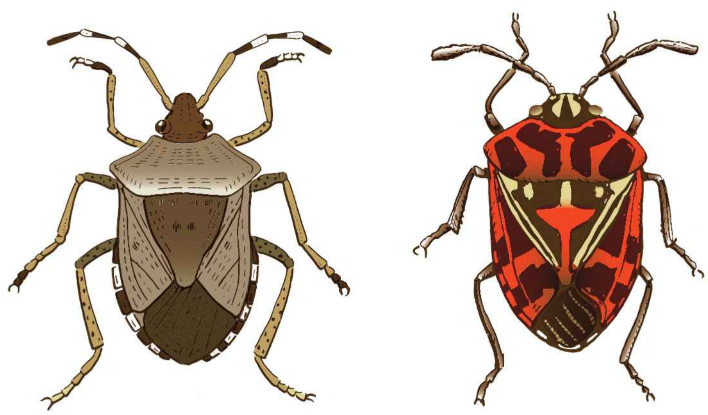
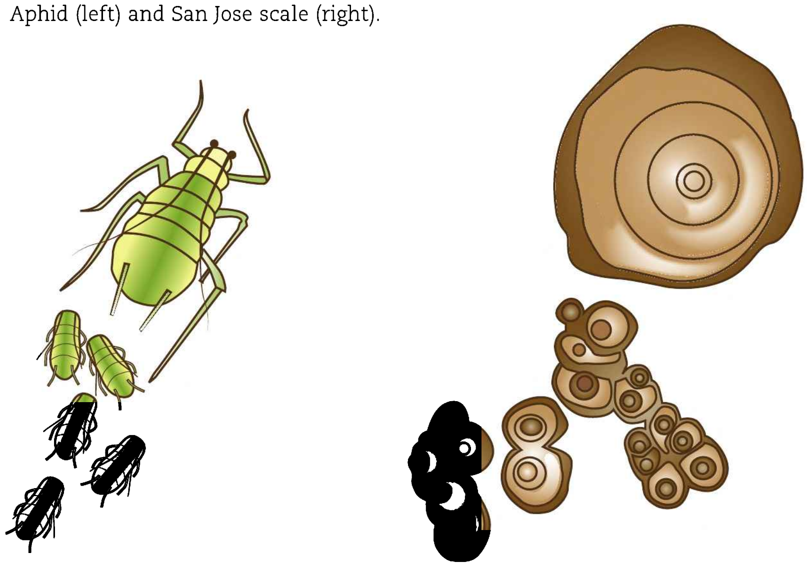


Figure 7.16

Aphid (left) and San Jose scale (right).



Aphids (fig. 7.16) come in many sizes, shapes, and colors (green, black, yellow, brown, red) and attack numerous vegetables, legumes, stone fruit crops, apples, and ornamentals. Dozens of species infest plants in California. Curled, distorted leaves and sticky honeydew exudates on leaves are strong signs of aphid infestation. Aphids have numerous generations per year in California's climate. Some species mate and reproduce sexually, producing eggs in fall or winter, but during the growing season most pest aphids in California reproduce asexually, with adult females giving birth to live offspring without mating or laying eggs. It has been found that the cabbage aphid has an average of 41 offspring per female and each female produces 16 generations from April to October. This means that a single female aphid can produce 1,560,000,000,000,000,000,000,000 aphids by the end of the summer.

A few aphids transmit viral diseases as they feed on young leaves and stems. Low to moderate populations of aphids can be tolerated in most home gardens. Aphids can be controlled by hosing them off with jets of water, by insecticidal soap or oil sprays, and by naturally occurring predators (lady beetles, syrphid fly larvae, lacewing larvae) and parasitic wasps.

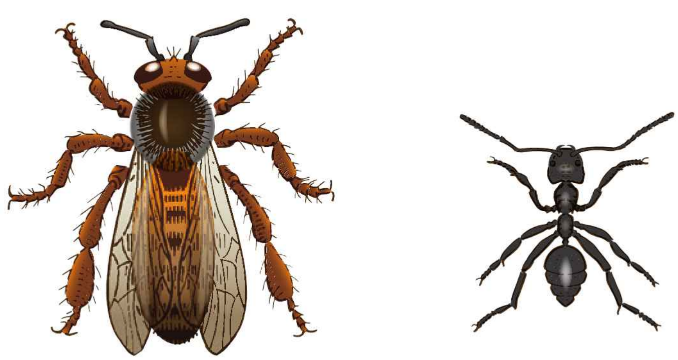
Leafhoppers feed on the underside of leaves, causing stippling; a few species (notably sharpshooters) transmit viruses and other diseases such as Pierce's disease of grapes. The many species of leafhoppers attack many hosts, including ornamentals, turf, beans, cucurbits, potatoes, eggplants, grapes, and apples. Leafhoppers can be tolerated in most home gardens. In any case, they are very difficult to manage because of their high mobility.

Scale insects (see fig. 7.16) are serious pests of fruit and nut trees, grapevines, and woody ornamentals. Two groups of scales are the armored scales and the soft scales. Armored scales are usually quite small, flat, and have a plate-like, hard shell (California red scale, walnut scale, oystershell scale). Soft scales (such as black scale, brown soft scale, lecanium scale, and Kuno scale) are larger and more convex in their mature stage and excrete honeydew, which attracts ants and causes sooty mold fungus to grow. Armored scales do not excrete honeydew. Several other types of scales, such as cottony cushion scale, sycamore scale, and oak pit scale, do not fit into the armored and soft scale categories. Adult female scales and many immature forms are sessile and can move only when they have first hatched or when they are molting. Many natural enemies attack scales, so often the best control of scales is eliminating the ants that protect the scales from natural enemies. If insecticides are necessary, a carefully timed oil spray during the dormant season or when scales are newly hatched generally provides the best control.

Mealybugs are oval, segmented, and covered with wax. They are common pests of house plants, greenhouse plants, and certain woody ornamentals and secrete a sticky honeydew.

Figure 7.17

Honey bee (left) and common ant (right).



Whiteflies are found on many plants including vegetables, ornamentals, and citrus trees. When these pests are disturbed on their hosts, clouds of the tiny, winged adult whiteflies fly into the air. The flat, legless nymphs excrete honeydew and cannot move except when they molt. Leaves of infested plants may turn yellow, get sticky, and have black sooty mold. In the Imperial Valley, the silverleaf whitefly transmits several viruses that devastate vegetable crops. They are attacked by a number of natural enemy predators and parasites. Insecticidal soap applied to the underside of leaves can help control whiteflies.

Hymenoptera: Bees, Wasps, Ants, Sawflies

Metamorphosis: Complete

Mouthparts: Chewing

Attributes: Larvae of wasps, bees, ants are legless, but most sawfly larvae have true legs. Adults have two pairs of membranous wings and soft or slightly hardened bodies.

The order Hymenoptera is large. Many of its members are important beneficials, including pollinators such as honey bees (fig. 7.17), leafcutter bees, and alkali bees, or natural enemies of many pest insects, such as parasites and predators of insects, such as paper wasps. Only a few wasps, such as yellowjackets, aggressively attack people. As a group, ants (see fig. 7.17) are important natural enemies of many insect pests, but some species, such as the Argentine ant, can be a problem because they feed on honeydew excreted by some pest insects (aphids, soft scales, mealybugs, whiteflies) and protect these pests from their natural enemies. Some species of ants invade homes and can cause structural damage. Sawflies are one of the few groups within the Hymenoptera that feed on plants; their larvae can be important pests of garden plants, shrubs, and trees.

The Amazing Honey Bee

A beehive has only one queen; her primary purpose is to lay eggs—2,000 per day. Fertilized eggs can develop into worker bees or queens, and nonfertilized eggs develop into male bees, called drones. A small hive may have 300 or so drones, and their only purpose is to mate with the queen. Worker bees are sterile females and number about 20,000 in a small hive. They collect nectar and pollen, feed the queen, cool and clean the hive, and are responsible for making new queens by giving a particular type of food (royal jelly) to selected larvae.

Isoptera: Termites

Metamorphosis: Gradual

Mouthparts: Chewing

Attributes: Termites (fig. 7.18) are small, soft-bodied insects that are sometimes confused with ants. However, termite antennae are straight, not bent, and their waists are thicker than those of ants. Various stages are winged or wingless.

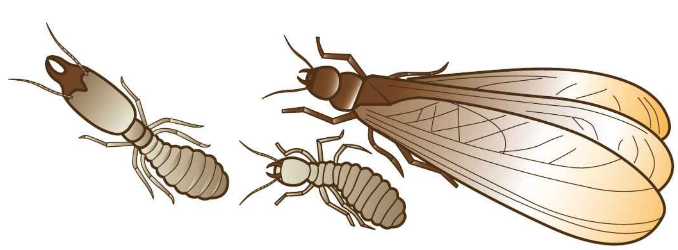
Termite colonies occur in the ground or in wood. Three major groups in California are the drywood, subterranean, and dampwood termites. All feed on wood and wood products; protozoa in their guts digest the cellulose in the wood. Subterranean termites build their nests in soil and normally require continuous contact with soil to get moisture for survival. When wood is in contact with soil, termites can burrow from the soil directly into the wood. If a barrier, such as a concrete slab, exists between the soil and wood, subterranean termites build earthen tubes to bridge the barrier. Subterranean termite infestations can destroy the structural integrity of a building.

Many species of drywood termites damage buildings, furniture, utility poles, fences, and piled lumber. Unlike subterranean termites, they do not require contact with soil. As their name implies, they attack dry wood and carry out their work completely inside the wood. Attics are common areas of drywood termite infestation. Often, the only evidence of their presence is a few small holes through which they push frass (fecal material and undecomposed wood formed into tiny, football-shaped pellets) out of the galleries.

Termites are organized into a caste system (reproductive caste, supplementary reproductives [swarmers], soldiers, and workers). Workers are white and usually sterile; they collect food and feed the queen, soldiers, and young. Soldiers are usually sterile, with large heads and mandibles; they fend off intruders. Reproductives have four nearly identical wings that are longer than their bodies.

Figure 7.18

Termite.



Lepidoptera: Moths, Butterflies

Metamorphosis: Complete

Mouthparts: Larvae, chewing; adults, sucking

Attributes: Larvae (caterpillars) are wormlike, voracious chewing feeders, with three pairs of legs on the thorax and often leg-like protuberances (prolegs) on the abdomen. Adults (fig. 7.19) are soft bodied, with two pairs of membranous wings covered with small scales. Adult mouthparts are coiled sucking tubes.

Larvae—cutworms, loopers, leafminers, skeletonizers, webworms, borers—cause cosmetic and economic damage to fruits, shoots, and leaves of all types of plants. Leaf-eating caterpillars (tomato hornworm, armyworms, loopers) chew irregular holes. Skeletonizers consume the leaf between the veins. Many small caterpillars roll leaves to form shelters. Codling moth, corn earworm (tomato fruitworm),

Figure 7.19

Swallowtail (left) and polyphemus (right).

Figure 7.20

Lacewing.

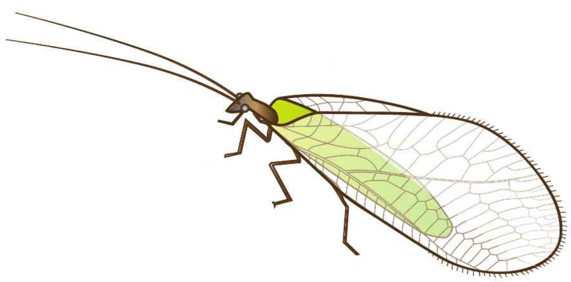
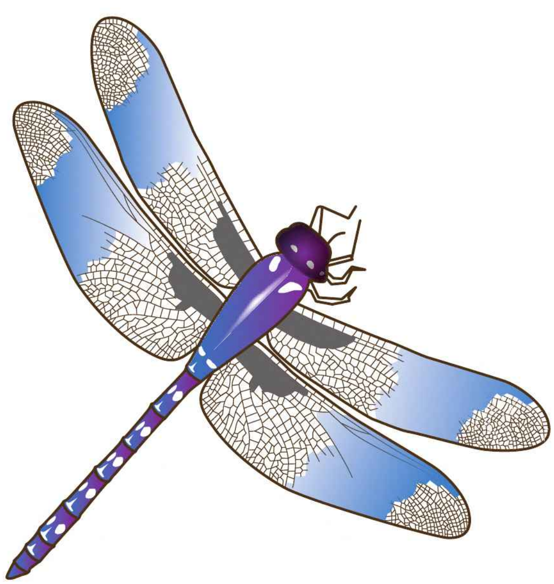


Figure 7.21

Dragonfly.



and other caterpillars that feed directly on fruit or nuts are more damaging, in general, than are leaf feeders. They blemish fruit surfaces, penetrate fruits, and bore into the core, leaving holes and open wounds for rot-producing bacteria and fungi. Codling moth larvae are the most serious caterpillar pest of apples, pears, and walnuts in California. They also attack stone fruit crops. For early detection in the vegetable garden, get close to the plant with a hand lens, turn over leaves, and inspect fruit. For fruit trees, use a ladder to inspect the tree canopy. The larvae of clearwing moths and carpenterworms bore into trunks and branches of trees. Many adult Lepidoptera feed on nectar; unlike larvae, adults are not pests. Some adult butterflies and moths are pollinators that are essential for healthy fruit set.

Neuroptera: Lacewings, Antlions

- Metamorphosis: Complete
- Mouthparts: Chewing
- Attributes: Adults have two pairs of membranous wings, about the same size with numerous cross veins, that are held rooflike over body at rest. Their antennae are long. Larvae are flattened, alligator shaped, and have prominent mandibles.

Most species of Neuroptera are predators of other insects. Lacewing larvae are important predators of aphids, psyllids, other soft-bodied insects, insect eggs, and mites. They are sometimes called aphid

lions because of their feeding habit. Green lacewing eggs are easy to recognize because they are laid at the end of tall, threadlike stalks, usually attached to foliage. Adult lacewings (fig. 7.20) are fragile in appearance with greenish or brownish transparent wings that have a fine network of veins. Wings are longer than bodies. Antlions feed on ants and other insects. Antlion adults resemble damselflies but are softer bodied and have conspicuous, knobbed antennae.

Odonata: Damselflies, Dragonflies

Metamorphosis: Gradual

Mouthparts: Chewing

Attributes: Adults have very short, bristlelike antennae, large eyes, and two pairs of elongate, membranous, many-veined wings that are similar in size and shape. Their abdomen is long and slender, with many bright colors.

Nymphs of damselflies and dragonflies are aquatic. Adults can fly. All life stages are predaceous, feeding on mosquitoes, midges, and other small insects, helping to keep their populations under control. At rest, damselflies fold their wings over their backs, whereas dragonflies (fig. 7.21) extend their wings horizontally.

Figure 7.22

Grasshopper.

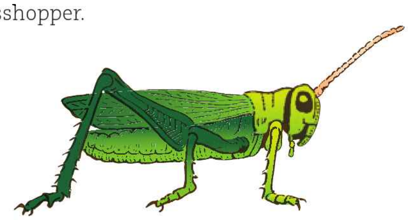
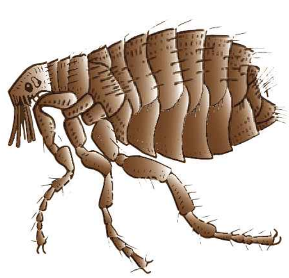


Figure 7.23

Flea.



Orthoptera: Grasshoppers, Locusts, Crickets

Metamorphosis: Gradual

Mouthparts: Chewing

Attributes: Moderate to large, hard-bodied adults, with two pairs of wings. Front wings are hard, leathery, and rooflike over the hind wings. Nymphs resemble adults, except for being wingless. Insects in this order "sing" by rubbing body parts against one another. Some have rear legs modified for jumping. Adults and nymphs damage plants.

Crickets and grasshoppers (fig. 7.22) only occasionally require control in home gardens. Populations of grasshoppers can build up in foothills and rangelands after a wet spring. In early summer, if grasshoppers migrate to fields and gardens, they can defoliate everything in sight.

Siphonaptera: Fleas

Metamorphosis: Complete

Mouthparts: Sucking

Attributes: Fleas are small (< 5 mm), wingless insects that often live as ectoparasites on birds and mammals. Adults have short antennae and a flattened body. The larvae are tiny, whitish, and legless and resemble maggots.

Adult fleas (fig. 7.23) move quickly and jump often. They suck and feed on the blood of the host and can cause hair loss in cats and dogs. Many fleas are not host specific. Fleas can also be important vectors of disease (bubonic plague, endemic typhus) as they move from wild hosts such as rats to domestic dogs. The larval flea lives in carpets, feeding on decaying organic matter. When controlling fleas, you must control both the adults and larvae.

Thysanoptera: Thrips

Metamorphosis: Intermediate, between Gradual and Complete

Mouthparts: Sucking-rasping

Attributes: Adult thrips (fig. 7.24) are minute (< 1 mm), slender, soft-bodied insects with two pairs of long, narrow,

membranous wings fringed with long hairs. The antennae are short. Adults range from yellow to black; immatures resemble adults but lack wings.

Some species of thrips are beneficial, such as the six-spotted thrips, which feeds on mites and other insects. Other thrips, such as citrus thrips and flower thrips, feed on plants and scar leaf and fruit surfaces with their rasping-sucking mouthparts. The cosmetic damage they cause to leaves is unattractive but usually does not reduce yield. Thrips attack citrus, raspberries, grapes, and numerous vegetables and ornamentals, and they may transmit plant diseases.

Thysanura: Silverfish, Firebrats

Metamorphosis: Gradual/none

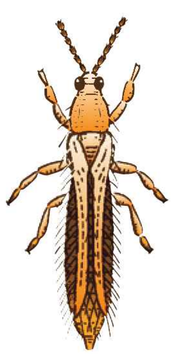
Mouthparts: Chewing

Attributes: Adults lack wings, have bristles on the tip of the abdomen, and are about $^{1}/_{2}$ inch long. Three tail-like bristly projections, or appendages, are attached at the rear end. Immatures resemble small adults.

Silverfish and firebrats (fig. 7.25) are household pests that feed on starchy substances such as glue, book bindings, starched clothing, paste in wallpaper, curtains, linens, silks, paper, and foods that contain starch.

Figure 7.24

Onion thrips.



Insect Movement and Spread

The adults of many insects have wings, and flight is a principal means of locomotion and spread into areas previously uninfested. Because moths are frequently night fliers, many species are not often seen as adults. Flying insects may locate host plants by odors emanating from the plants (kairomones), by chemical messages released by the first few insects reaching the host (aggregation and sex pheromones), or by other means, such as color. They then lay eggs on the plant, giving rise to a larval infestation.

Most adult insects and most larval stages have legs and can walk from plant to plant or from overwintering and hiding sites to plants. Like some flying insects, certain walking insect pests are most active at night, and it may be necessary to inspect plants by flashlight to determine the cause of disappearing foliage.

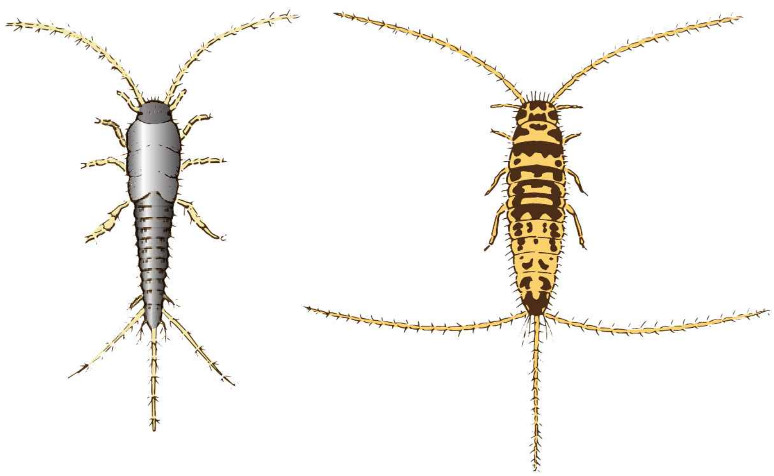
Wind or ordinary air currents can transport pests from place to place. For example, newborn scales, called crawlers, are tiny, flattened insects easily blown from one plant to another. Crawlers then settle down on the plant, insert their long, slender mouthparts into the host tissue, and usually remain there for the rest of their lives. Scales in the crawler stage may also be transported on the feet of birds or visiting insects. Spider mites are carried long distances by air currents, which may explain infestations on house plants believed to be pest-free at purchase. Spider mites and many other pests enter homes through open doors and windows.

Some caterpillars produce silken strands by which they "string down" from vegetation, distributing their populations on a tree or shrub. If the larvae are general feeders, they may string down to understory vegetation, causing damage to plants other than those on which the eggs were laid.

Purchase of already-infested plants at the nursery or garden center is a very sig-

Figure 7.25

Silverfish (left) and firebrat (right).



nificant means of insect movement and spread. Inspect new plants for pests before placing them in your garden, although it may be difficult to inspect plants sufficiently to detect the eggs or tiny larvae of some pests. Consider isolating newly purchased house plants and not placing them in a room or home greenhouse with existing plants until it can be determined that they are free from pests.

Beneficial Attributes of Insects

Not all insects are bad. In fact, of the 92,000 species that have been identified in the United States, about 87,000 (95%) are either good or neutral. Many insects play a beneficial role in the landscape and garden. These "good bugs" serve as predators or parasites of other insects, nematodes, and weeds. Called natural enemies, beneficials eat or prey on "bad bugs," which can result in control of the pest. Classic examples of predators are the lady beetles, lacewings, syrphid (hover) flies, and the preying mantis. Examples of parasites are the very tiny *Ichneumon* and *Trichogramma* spp. wasps. Probably the most well known benefit from beneficial insects is the pollination of many of our fruits, vegetables, and ornamentals. Pollinators are very important in the production of almonds, squash, melons, kiwis, apples, avocados, cherries, pears, plums, and other crops. About 80% of all of the pollination of our crops comes from honey bees and other pollinators. Many additional benefits result from the commercial use of honey bees to pollinate our crops, including the sale of honey and other byproducts such as wax, pollen, propolis, and royal jelly.

Insects are beneficial in many other ways. Forest insects help decompose downed forest trees to make room for new seedlings. Dermestid insects clean skeletons for museums. Cochineal scale insect bodies produce a bright red pigment used in cosmetics, medicinals, and food products; although the dye has been largely replaced by synthetics, it is still used as a biological stain and by some food manufacturers. Silk comes from the silkworm cocoon, which is the stage of the caterpillar just before it becomes a moth. To produce 1 pound of silk for a dress requires 2,000 to 3,000 silkworm cocoons.

Insect Outbreaks

Insect pests do not occur in the same numbers each year. The reason populations fluctuate is not completely understood, but it involves temperature, rainfall, availability of suitable food, and the presence or relative absence of parasites, predators, and disease-causing agents. Because insect pests are numerous one year does not mean that their populations will be as great a problem the next year.

Exotics and Invasive Pests

Exotic pests are species that come into one region from a different region; invasive pests are species that rapidly colonize

a region. Exotic pests are frequently brought in accidentally on plant material sold in nurseries, hidden in luggage, on firewood, or transported in fruits and vegetables brought across state borders. Exotics can become invasive pests, often because they are no longer under control of predators or diseases that limited their numbers in their native habitat. Examples include the glassy-winged sharpshooter, Diaprepes root weevil, and the light brown apple moth (LBAM). Once established, invasive species are extremely difficult to eradicate and can cause not only ecological disruption but economic problems as well. Everyone has a part to play to keep exotic species from coming into California and becoming invasive throughout the state by not bringing foreign plant or animal material into California.

Insect Distribution

Some pest insects are widely distributed throughout the world, damaging plants in numerous countries on several continents. Many other insects are more regional in their occurrence. Although air travel has made it much easier for pests to be introduced into new areas, most insect pests have rather precise climatic and other environmental requirements that limit where they occur, survive, thrive, and spread.

Within California, the climatic differences among coastal, interior valley, and mountainous areas greatly influence the ability of many pests to survive in a given region. For example, the cypress tip miner *(Argyresthia cupressella)* is limited as a pest to regions strongly influenced by coastal fog. It is not commonly found in the Central Valley, the Sierra, or the mountainous regions of northern California, even though its host plants grow there.

Diagnosing Plant Problems Caused by Insects and Mites

The diagnosis of plant problems is aided by knowledge of what pests attack the plant species of concern in a given area. Narrowing the possible causes of plant problems is a cornerstone of problem diagnosis. See also chapter 21, "Diagnosing Plant Problems," for further diagnosis concepts and information.

Several factors may work collectively to cause poor plant performance. For example, drought-stressed pine trees (sometimes due to poor cultural practices) are often selected for attack by bark beetles and are also less able to resist attack.

A single pest may cause more than one symptom. Aphids, for example, often cause twisted or cupped leaves and yellowed foliage, but they also produce honeydew, which may lead to sooty mold that blackens plant parts, depending on the species of aphid and host. Greenhouse thrips cause bleaching of foliage and always leave behind spots of varnish-like excrement (see table 7.1). Approaching the diagnosis of insect-related plant problems first through signs and symptoms is particularly important when pests are no longer on the plant. However, always confirm a diagnosis by also searching the sample to see if the pest is present.

Knowing the kinds of symptoms that various pests produce narrows the possible cause. Refer to the diagnostic tables in *Pests of the Garden and Small Farm* and *Pests of Landscape Trees and Shrubs* for comprehensive information. Both publications are excellent resources that master gardeners should consult routinely for diagnosing and managing plant pest problems. See also the following section and table 7.1 for brief comments on the subject.

Tips for Diagnosing Insect Problems

Host plants. Most insects and mites show specificity in their choice of host plants. Some are general feeders, but the majority are not. Knowing the name of the affected plant is therefore extremely helpful and frequently essential in determining the identity of the pest, because much of the reference literature is organized by the host plant that is being attacked.

Other kinds of problems. Most of the problems brought to your attention will be attributable to factors other than insects or mites.

Cause not evident on plant. The cause of poor plant performance may not be evident on the plant sample given to you for diagnosis. For example, wilted leaves may be caused by a pest attacking roots. The presence of insects or mites does not always mean that they are the real cause of the problem.

Entire plant dead? If the entire plant is dead, the chances are great that insects or mites were not the cause of death. With a few exceptions, insects and mites seldom kill their host plants, but diseases often do.

Too late? By the time many people notice a pest problem and seek advice, it is often too late in that particular growing season to take corrective action. In some cases, a pest insect may be gone, and only the damage remains.

Inspect the damage. People tend to magnify the actual size of an insect when they are describing it. In general, do not make recommendations based on the client's verbal description. Observe the damage and the insect itself to avoid incorrect identification. Use a hand lens, when needed.

Table 7.1.

DIAGNOSIS OF ARTHROPOD PLANT PROBLEMS BASED ON EVIDENCE OF PEST INFESTATION

What the damage looks like	Possible pests
chewed or tattered foliage or blossoms	larvae of moths or butterflies, larvae and/or adult beetles, sawfly larvae, grasshoppers, katydids, earwigs, snails and slugs
stippled (flecked), yellowed, bleached, or bronzed foliage	spider mites, leafhoppers, plant bugs, lace bugs, thrips, aphids, psyllids, whiteflies
distortion of plant parts	aphids, thrips, cynipid (gall) wasps, larvae of certain gall moths, eriophyid (gall, blister, bud, or rust) mites
dieback of plant parts	scale insects, moth or beetle larvae that bore, cynipid (gall) wasps, horntails
insect-related products	honeydew/sooty mold: aphids, leafhoppers, soft scales, mealybugs, psyllids, whiteflies
	dark fecal specks: greenhouse thrips, lace bugs
	tents, webs, silken mats: tent caterpillars, webworms, leafrollers
	spittle: spittlebugs
	cast skins: aphids, leafhoppers, lace bugs
	pitch masses: larvae of certain moths, e.g., sequoia pitch moth
	pitch tubes: certain scolytid beetles
	flocculence (cottony waxy material): adelgids, mealybugs, certain scales, aphids, whiteflies
	slime: snails and slugs

Incorrect identification leads to ineffective control measures, unnecessary expense, and potential damage to beneficial insects.

Look for signs of feeding. Insects and mites must feed to survive and reproduce. Evidence of their feeding will nearly always remain on the plant even after the insect or mite is gone. Most signs and symptoms of insect and mite activity fit into one or more of the categories described in "Insect Feeding," above, or in the discussions on common insects and common insect relatives.

Admit doubt. Do not be afraid to say that you do not know the answer. When in doubt, do not make a diagnosis. But do mention that you will look into it further or ask for help from a specialist.

Stick with UC advice. Master gardeners represent the University of California. Make a diagnosis or give advice based on information that has been verified by UC experts. Consult UC resources listed at the end of this chapter.

Principles and Major Methods of Managing Insect Pests

Integrated Management of Insect Pests

The University of California encourages gardeners to manage insects and other pests using an integrated pest management (IPM) strategy. A central concept in IPM is that of integrating several control methods, such as resistant varieties, cultural practices, biological controls, and the least-toxic pesticides, for long-term management of pests. An IPM approach encourages methods that provide long-term prevention or suppression of pest problems with minimal impact on human health, the environment, and nontarget organisms.

A fundamental concept of IPM is that a certain amount of insect damage can be tolerated. Broad-spectrum pesticides are used only as a last resort when careful monitoring and preestablished guidelines indicate that they are needed. IPM programs can be carried out in most gardens with almost no use of pesticides that are more toxic than soaps, horticultural oils, or microbials.

When possible and practical, take action to prevent insect problems before they occur by choosing resistant varieties, providing optimal conditions for plant growth, and taking preventive action against insects known to be a problem in the area. Purchase insect-free plant material from reputable suppliers. Once the home garden and landscape are planted, inspect shrubs and landscape trees occasionally and vegetables and fruit trees at least once a week (twice a week at the peak of the growing season or more often if it appears that a problem may be brewing) for possible insect pests, natural enemies, or signs of an infestation.

When you do find insects, try to identify them, or at least rule out the possibility that they are pests, using the information and principles learned in this chapter and other UC resources. When checking trees, check a few leaves on each side of the tree as well as the trunk. Examine fruit on plants and any that have fallen to the ground. If plants appear wilted, inspect the roots to check for signs of pathogens or root-infesting insects. If an insect or pathogen does not seem to be associated with the symptoms, try to determine whether one of the abiotic noninfectious disease factors highlighted in chapter 6 may be the cause. As part of this process, evaluate fertilization and irrigation regimes, soil quality, drainage, and the prevailing weather. Keep notes of your observations, the date, time of day, stage of crop development, any intervention that you took, and the results.

Pest management strategies will most likely fail if the pest is not identified properly, since the control action will probably

not be effective against the offending organism. Some problems may require professional diagnosis. The county agricultural commissioner's office and the UC Cooperative Extension farm advisor may be able to help identify a pest problem or direct you to professional diagnostic services. See chapter 21 for more information on diagnosing plant problems.

Six major methods are used to control insect pests. This section briefly presents these main control strategies; see chapter 9, "Safe and Sustainable Pest Management," for more detailed discussion on pest control and management.

Legislative Control

Federal, state, and county quarantines are sometimes established in an attempt to prevent the movement of certain goods and commodities that are likely to harbor pests not known to occur at their destination. Quarantines have been established in California to prevent the entry or further spread of pests such as glassy-winged sharpshooter, Asian citrus psyllids, Japanese beetle, Mediterranean fruit fly, and Dutch elm disease. Maintenance of inspection stations at the borders of California is another form of legislative control. Master gardeners are not directly involved in this type of control, but they can cooperate in these efforts by submitting specimens of suspect insects to the local county agricultural commissioner for confirmation of identification.

Physical, or Mechanical, Control

Physical, or mechanical, controls directly kill or trap pests or exclude them. Examples of physical methods to control insect pests include placing cardboard or tar paper collars around young tomato, cabbage, or other transplants to exclude cutworms; handpicking tomato hornworm larvae from plants; and screening windows to prevent the entry of flies and mosquitoes. Physical control methods may be preventive or curative.

Cultural Control

Cultural control techniques include modification of normal gardening practices to prevent or reduce pest problems. Examples of cultural pest insect controls include planting a pest-resistant variety or species of vegetable, fruit, or ornamental; rotating from year to year the location of tomatoes, eggplant, and other vegetables susceptible to Verticillium wilt; and maintaining a cover crop of turf or mulch in the home orchard to discourage a spider mite buildup occasioned by dust.

Biological Control

Biological control entails the use, preservation, conservation, and augmentation of parasites, predators, and disease-causing microorganisms (pathogens) to bring about the control of insect pests. The most important biological control agents are the natural enemies that are already established in the garden. Virtually every insect and mite pest has several natural enemies that attack it, and in many cases, these biological control agents can keep the pest below damaging levels most of the time. Many insect and mite outbreaks occur because a broadly toxic insecticide was applied to control a pest, and many of the natural enemies were also killed. Avoiding the use of certain insecticides, or avoiding the use of them at certain times, may help to preserve the natural balance of pest populations. Learning to recognize predators and parasites and the signs of parasitization, and extending this knowledge to the homeowner, is extremely useful for the master gardener.

Some biological control agents can be purchased for release and use in the garden. Lady beetles and lacewings can often be found for sale in nurseries or ordered online, then released in the garden. The insect pathogen *Bacillus thuringiensis* (Bt), a bacterium sold commercially under many brand names, is quite specific in its action against certain caterpillar pests and causes minimal harm to other forms of insect life in other orders. (For more infor-

mation about Bt, see chapter 9, "Safe and Sustainable Pest Management.")

UC entomologists travel worldwide in search of biological controls (natural enemies) for some of the more aggressive pest insects that cause economic damage to California agriculture. In recent years, UC entomologists have imported tiny wasps that parasitize certain aphids, scales, psyllids, whiteflies, beetles, and other insects. In the case of aphids, the adult wasp deposits its eggs inside the pest aphids. After the wasp eggs hatch, the larvae feed inside the aphids. When the parasitized aphids die, the body becomes a crusty, hard mummy. The larvae emerge from the dead aphid as adult wasps.

Chemical Control

Chemicals for insect and mite pest control include insecticidal soaps, horticultural oils, various inorganic materials, botanical compounds, microbial insecticides, and synthetic organic materials. Technically, all of these chemicals are insecticides, though their toxicity to pests and to humans and other animals varies greatly. Some chemicals are used in advance of a pest infestation as preventive treatments; however, most are used after the infestation begins. Botanical insecticides are organic insecticides derived from plant sources and include pyrethrum (or pyrethrins), and azadirachtin, or neem extract. The main advantages of soaps, oils, microbials, and botanical insecticides are their short residual activity, lower impact on nontarget organisms, and in many cases, application up to the day of harvest. Other very safe pesticides include horticultural oils (based on petroleum or plants), insecticidal soaps, and insect growth regulators. Synthetic materials have the advantage of lasting longer, and although they sometimes reduce the pest populations more effectively, they may be toxic to natural enemies.

Because of the toxic nature of many pesticides, devote special attention to their proper use. For more detailed information on pesticide labeling, types of pesticides, modes of action, application methods, formulations, additives, legal requirements, prevention of pesticide poisoning, protective equipment and clothing, application equipment, calibration of sprayers and spray patterns, storage and disposal, and environmental concerns, see chapter 9. For additional information about pesticides and their relative effectiveness, refer to *Pests of the Garden and Small Farm* and *Pests of Landscape Trees and Shrubs*. Consult the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden, for suggestions on pesticides for specific pests.

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Weed Science 8

Richard H. Molinar

Learning Objectives

Know the definition of a weed and the concept of an invasive plant. Know the traits that make controlling them difficult.

Develop an understanding of basic weed classification and biology as a prerequisite to choosing effective weed control strategies.

Learn basic weed control principles and methods. Learn about the four weed management strategies: cultural, mechanical/physical, biological, and chemical.

Learn basic terminology associated with herbicides. Develop skills for selecting the proper herbicide. Develop basic understanding of herbicide formulations and application methods.

Learn practical methods for controlling weeds in turf, ornamentals, and vegetable gardens.

This chapter is intended to be used in conjunction with chapter 9, "Safe and Sustainable Pest Management," in this book and with *Pests of the Garden and Small Farm* (Flint 1998); *Pests of Landscape Trees and Shrubs* (Dreistadt 2004); *Weeds of California and Other Western States* (DiTomaso and Healy 2007); and the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden. Also see the "UC Guide to Healthy Lawns" on the UC IPM website.

Weed Science

Definition and Function of Weeds

The simplest definition of a weed is "a plant growing where it is not wanted." From the point of view of the home gardener, many plant species can become weeds. Plants are called weeds when they interfere with the intended use of land and water resources, cause health problems, or reduce aesthetic value of a site. For example, a cantaloupe vine may be desirable in the garden, but in the front yard flower bed, it may be a weed. On the other hand, black mustard is a weed in the garden, but on a hillside prone to erosion, it is a desirable plant. In a vegetable garden, a dandelion may be a cultivated salad green, but in a lawn, it is classified as a weed. In gardens the intended use determines whether a plant is considered a weed. A distinct group of weeds that occur in natural habitats are known as invasive plants (see the discussion on this topic below).

Scientists who specialize in studying weeds point out that many weeds have specific characteristics that set them apart from most garden plants, making competitiveness, persistence, and perniciousness in cultivated plantings a concern. These traits make weeds undesirable in home gardening and landscapes and an economic hardship to agriculture when they are not controlled. Weed scientists point out that weeds are particularly noteworthy for their seed dormancy, long-term survival of buried seed, abundant seed production, rapid population establishment, capacity to occupy sites disturbed by human activities, and multiple adaptations for spread, often including vegetative reproductive structures.

Of the more than 250,000 plant species identified by scientists, only 250 plant species (0.1%) are major weed problems in world agriculture. Despite the limited number of species, weeds are extremely detrimental to crop production in California and are the number-one pest problem in the garden and landscape. Statewide, more dollars are spent to control weeds than to control any other plant pests, and losses caused by weeds typically exceed losses from any other category of agricultural pest. Some weeds are so difficult to control that California and other states have passed legislation identifying them as noxious weeds, providing for their intensive control or eradication by law.

Disadvantages of Weeds

Weeds compete with crops for limited supplies of water, mineral nutrients, sunlight, and infrequently carbon dioxide and oxygen. As a result of weed competition, crops and landscapes often experience reduced growth, vigor, yield, and crop quality, and under severe conditions experience increased mortality. Factors that allow weeds to outcompete desirable plants include prolific seed production, seed dormancy, and protected underground reproductive structures such as bulbs and rhizomes that withstand environmental stress and remain viable for years. Many weeds are more

tolerant of heat, drought, and floods than domesticated crop plants, and some weed populations are even resistant to herbicides that were formerly effective in their control.

Weeds can serve as hosts for insect pests and pathogens. Weeds increase the likelihood of disease because they can serve as an overwintering host when the crop is not growing.

Weeds provide cover or food for vertebrate pests, especially rodents, increasing those pest problems.

Weeds are allergens to many people. Weed pollen contributes to hay fever allergies, and weed foliage (poison oak) causes skin dermatitis in sensitive people.

Advantages of Weeds

Because the detrimental effects of weeds generally outweigh their virtues, good horticultural practices should promote conditions most favorable to desirable plants and least favorable to weeds. Weeds do have some redeeming features, however. They

- reduce dust and soil erosion
- provide cover and food for vertebrates such as birds
- are a nectar source for honey bees
- create habitat for beneficial predator or parasite populations
- provide a source of additional soil organic matter
- serve as a potential source of therapeutic pharmaceuticals
- may be eaten (e.g., purslane, lambsquarters, dandelion, and nettle)

Invasive, or Noxious, Plants

Invasive, or noxious, plants are a distinct group of weeds that occur in natural habitats. Invasive plants are non-natives that infest natural ecosystems, including wildlands, rangelands, and pastures, degrading their environmental and functional characteristics. An important difference between invasive plants and many garden weeds is that invasive plants can disperse, establish, and spread in uncultivated areas. Because of this, they are much more problematic in natural environments than are typical weeds.

Many of the characteristics required for a plant species to be successful as a landscape or garden ornamental are also qualities that can lead to invasiveness in natural settings (table 8.1). These shared characteristics are the reasons that 48% of the invasive plant species had their origins in the horticultural trade.

Impacts of Invasive Plants

Invasive plants can invade natural areas, such as parks and other natural open spaces, and can disrupt natural ecological processes, displace native plants, and alter the habitat for birds, insects, and other wildlife. From an economic standpoint, invasive species can reduce livestock forage quality and quantity, jeopardize animal and human health, increase the threat of fire or flooding, interfere with recreational activities, and lower land value. Aquatic invasive weeds can impact the movement and navigation of private

Table 8.1.

CHARACTERISTICS THAT MAKE NURSERY AND INVASIVE PLANTS SUCCESSFUL

Characteristic	Nursery plant	Invasive plant
germination and planting	easy to propagate and establish	broad germination requirements and ease of establishment
growth	grow rapidly	grow rapidly
reproduction	produce abundant flowers	prolific seed producer with successful dispersal mechanism
environmental fitness	ability to grow in many regions and remain hardy	ability to tolerate drought and salt stress and spread to many regions in the state
pest resistance	free of insect pests and diseases	free of natural enemies and diseases

and commercial vessels, block irrigation systems, and impede livestock access to water (for more information about invasive noxious weeds, see the California Department of Food and Agriculture website, cdfa.ca.gov/plant/ipc/).

Invasive Plants of California

California boasts the greatest amount of natural botanical diversity of any state in the United States, with nearly 5,000 native plant species. In addition to native species, about 1,300 non-native species have become established in the state. About 200 to 300 of these are weeds of agricultural crops, turf, or gardens. The remaining 1,000 or so are naturalized plants of wildlands or disturbed noncrop areas, some of which are important invasive plants.

The California Invasive Plant Council (Cal-IPC), a nonprofit organization, has created a useful inventory of invasive plants. Using a process based upon 13 criteria, they have listed about 200 species as threats to California's wildlands (see the Cal-IPC website, cal-ipc.org).

Prevention Programs

Cal-IPC has promoted horticultural alternatives to invasive plants. They recommend native and non-native plants that have the same form or function as the undesirable species but are not invasive in wildland or natural areas. This organization has an excellent website, and their publication "Don't Plant a Pest" has excellent information about what to plant. Another organization with useful information and publications on their website is Plant Right, plantright.org.

Remind people that bringing in plants or seeds from foreign countries without the proper authorization and inspection is a federal offense, and purchasing plants not currently grown under California standards through the Internet from out-of-state sources may also be illegal. Several plants on the state noxious weed list, such as purple loosestrife and saltcedar, can be readily obtained from seed through the Internet or in mail-order catalogs.

Invasive Plant Control

Invasive plants can be controlled using many of the same tools used to control horticultural and agricultural weeds, particularly mechanical and chemical control. In many cases, integrated approaches using combinations of methods are most effective. Caution must be exercised when suggesting management options in natural areas. Recommendations should be provided by professionals familiar with these situations. When in doubt, refer clients to a UC Cooperative Extension advisor.

Weed Classification

Identification of a weed (its common name and/or genus and species) is very important for determining effective management strategies. Knowing the identity of a weed is the first step in learning about its life cycle, growth, and development. Several weed identification references are available for California residents that provide photographs, identification keys, and physical descriptions to help with weed ID. Two commonly used publications are the two-volume *Weeds of California and Other Western States* (DiTomaso and Healy 2007) and the related *Weed Pest Identification and Monitoring Cards* (DiTomaso 2013), as well as *Weeds of the West* (Burrill et al. 2006). There is an excellent weed gallery on the UC IPM website, ipm.ucdavis.edu/PMG/, that can also be very useful in helping to identify weeds. Weeds are often classified by the plant family in which they are members, by their growth habit (annual, biennial, or perennial), and by effective control methods. The majority of weeds belong to a few plant families. General categories used to classify weeds are described briefly below.

Binomial Classification

Identifying a weed by its scientific (Latin) name ensures that everyone is referring to the same plant. A given plant may have many common names, depending on the region or state. For example, spotted spurge *(Euphorbia maculata)* also goes by the names milk purslane, prostrate spurge, spotted pulsey, and sandmat. On the other hand, a single common name may also refer to several very different species. Identification by genus and species is most important for scientific publications, but for master gardener purposes, the common name will probably suffice.

Life Cycle and Season Classification

The majority of weeds can be classified as annuals, biennials, or perennials.

Annuals complete their life cycle from seed to seed in 1 year or less. They grow, set seed, and die, so that only new plants that germinated from seed appear the following year. In some cases, seed may germinate the same season they are produced. There are two kinds of annual weeds: winter and summer. Winter annuals germinate in the fall, live through winter, and produce seed during the winter and spring. Summer annuals germinate in the spring and produce seed in summer or fall. Summer annuals, such as lambsquarters, spotted spurge, crabgrass, and pigweed, generally start to germinate about March 1 in Central California and continue growing throughout the summer. However, spotted spurge, for example, has germinated as early as January 30 during a few warm days, then remained as a seedling until the weather warmed up again (see sidebar). Crabgrass germinates when the soil temperature 3 inches deep is 55°F for three consecutive days. Knowing whether the weed germinates in the spring, winter, summer, or fall is critical for effective timing of management techniques. Mallow, groundsel, and annual bluegrass are winter annual weeds that begin to germinate about September 1 in Central California and continue germinating through the winter and spring.

Biennials generally complete their life cycle in 2 years. In the first year, they produce vegetative growth: leaves, stems, and a root system. In the spring and summer of the second year, biennial weeds flower, set seed, and die. Biennial weeds are not as serious a problem as annual weeds because gardeners generally remove them before they set seed. Bull thistle, oxtongue, mullein, and wild carrot are examples of biennial weeds.

Perennials live longer than 2 years and usually have a more extensive root system than do annuals and biennials. Young perennials can be controlled with cultivation, but once established, perennials are difficult to eradicate. Simple perennials,

All About Spotted Spurge

- Scientific name: *Euphorbia (Chamaeyce) maculata*.
- Stems secrete a milky latex that can be caustic.
- About six different *Euphorbia* spp. in California.
- A single plant can produce over 2,000 seed.
- Germinates at 60° to 100°F.
- Seedpods are very small capsules containing three seed.
- Plants have germinated as early as January 30.

Photo: C. Elmore

such as dandelion, reproduce only by seed, whereas creeping perennials, such as bermudagrass and woodsorrel (oxalis), can spread aggressively via vegetative structures (stolons, rhizomes, tubers, bulbs) and seed. Some perennials become dormant in the winter, only to send out new shoots in the spring. Examples include bermudagrass, johnsongrass, and dallisgrass. Nutsedge, bindweed, and poison oak are also common perennial weeds. Certain woody perennials such as tree-of-heaven, or stink tree, (*Ailanthus altissima*), can become very problematic in landscape and noncrop areas.

Table 8.2.

WEED TYPES

Type	Scientific name	Common name
annual broadleaf	*Amaranthus* spp.	pigweed
	Chenopodium album	lambsquarters
	Malva parviflora	mallow
	Portulaca oleracea	purslane
	Senecio spp.	groundsel
	Xanthium strumarium	cocklebur
	Euphorbia maculata	spotted spurge
	Sonchus oleraceus	common sowthistle
perennial broadleaf	*Convolvulus arvensis*	field bindweed
	Datura meteloides	tolguacha
	Oxalis spp.	oxalis
	Solanum elaeagnifolium	horsenettle
annual grass	*Digitaria* spp.	crabgrass
	Echinochola crus-galli	barnyardgrass
	Poa annua	annual bluegrass
	Setaria spp.	foxtail
perennial grass or sedge	*Agrypyron repens*	quackgrass
	Cynodon dactylon	bermudagrass
	Cyperus spp.	nutsedge
	Lolium perenne	perennial ryegrass
	Sorghum halepense	johnsongrass

Broadleaves and Grasses Classification

Two taxonomic groups of weeds recognized by plant biologists and weed scientists are dicots (broadleaves) and monocots (grasses and sedges). Weed specialists commonly classify weeds as annual or perennial broadleaves and annual or perennial grasses. The classifications in table 8.2 provide useful information about the classification of weeds. Other classifications, less important to the home gardener, are the weed's uses (whether the weed is edible or poisonous to humans or livestock) and regulatory status (whether any laws have been passed regarding the weed's noxiousness).

Sources of Weed Problems

Weed seeds are already present in most soil before any gardening or crop production activities occur. According to some sources there may be as many as 140 weed seeds per pound of cropland surface soil (equivalent to 200 million seeds per acre). Also, weed seed contaminants (impurities) can occur in packages and containers of crop seed.

Weeds have several unusual and effective mechanisms for seed dispersal. Certain weed seeds are able to survive the digestive tract of animals (table 8.3) and can accom-

Table 8.3.

PERCENTAGE OF VIABLE SEEDS PASSED BY ANIMALS (BASED ON TOTAL NUMBER OF SEEDS FED)

Plant seed	Calves	Horses	Sheep	Hogs	Chickens
field bindweed	22.3	6.2	9.0	21.0	0.0
sweet clover	13.7	14.9	5.4	16.1	0.0
velvet leaf	11.3	4.6	5.7	10.3	1.2
smooth dock	4.5	6.5	7.4	2.2	0.0

Source: Kingman and Ashton 1975.

pany an application of uncomposted manure to the soil (this is more of a problem with dairy manure than with bird manure). Proper composting of manure kills most weed seeds (see the section on composting in chapter 3, "Soil and Fertilizer Management"). Many weeds are well adapted for dispersal by wind. The seed of some species can easily become airborne or attach to clothing and animals. Birds and other animals disseminate weed seeds through eating fruit or seed of weedy plants, and some weed seeds can attach to animal skin, feathers, or fur. Gardening equipment, such as an unclean rototiller, lawn mower, or leaf blower, can inadvertently disperse weed seeds. Clean plant debris and soil from equipment between uses in different locations, and take the same precautions when using equipment borrowed from a neighbor or friend.

Weed Management Principles and Methods

Principles

Weed management is an easy concept in theory: simply remove the unwanted plants and prevent new ones from growing. However, in practice, weeds are difficult to control because they are so well adapted to the garden and landscape. Unlike crops that have been selected by plant breeders to germinate uniformly, weeds produce abundant numbers of seed that germinate unevenly. Dormant weed seeds do not germinate even when conditions are favorable, which complicates control. Because weed seed reservoirs (the soil seed bank) may remain viable for many years, a basic principle of control is to overcome the weeds' survival mechanisms in the soil. For annuals, the objective is to prevent seed production and to deplete seed reserves in the soil. For hardy perennials, the objective is to destroy underground vegetative reproductive organs and prevent seed production. Although diligent application of this principle should, in theory, lead to weed eradication, it is seldom achieved in practice. Controlling weeds is a continuous part of gardening and agriculture. Maintaining a crop in a superior competitive position requires the gardener to modify some aspect of the environment or exploit key biological differences that favor the crop over the weed, minimizing the competitive advantage of weeds.

The goal in any weed management program is to select the most effective practice that is least harmful to people and the environment and to apply it at the proper time—which always means not waiting until after the weed has set its seed. It has been said that "a year of seeds means decades of weeds." Tables 8.4 and 8.5 show that weeds can reproduce in large quantities; some weeds can produce thousands of seed that can live for many years. Even a 1% viability presents the potential for a large number of weeds to grow from one single plant.

Table 8.4.

SEED PRODUCTION AND VIABILITY OF SELECTED WEEDS

Scientific name	Common name	Seed per plant	Percent viable after 38 years
Verbascum thapsus	mullein	223,200	48
Amaranthus spp.	redroot pigweed	117,400	—
Sorghum halepense	johnsongrass	80,000	—
Chenopodium album	lambsquarters	72,450	7
Portulaca oleracea	purslane	52,300	—
Capsella bursa-pastoris	shepherd's purse	38,500	—
Rumex crispus	curly dock	29,500	1
Avena fatua	wild oats	250	—

Sources: Adapted from California Weed Conference 1989, p. 31; Radosevich,Holt, and Ghersa 2007, p. 125; Ashton et al. 1991, p. 23.

Note: — = unknown.

Table 8.5.

VEGETATIVE REPRODUCTION OF SELECTED PERENNIAL WEEDS

Scientific name	Common name	Time	Potential vegetative production of single plant
Convolvulus arvensis	field bindweed	1 year	2.5 ft in diameter with roots 4 ft deep after 1 year
Cyperus esculentus	yellow nutsedge	1 year	1,918 plants (from one tuber)
Sorghum halepense	johnsongrass	14 weeks	85 ft of rhizomes after 14 weeks
Typholia latifolia	cattail	6 months	10 ft in diameter (rhizomes) after 6 months

Source: Adapted from Aldrich 1984, p. 93.

Methods of Weed Control

From the beginning of agriculture to the middle of the twentieth century, the plow and hoe were the primary methods of weed control. Burning, flooding, smothering weeds, and crop rotation had been employed for many years, but substantial progress in controlling weeds in production agriculture did not occur until the discovery of synthetic herbicides in the 1940s, when the weed-controlling properties of the synthetic plant hormone 2,4-D were recognized.

For the home gardener, several alternatives to chemical weed control methods are available, because of the small scale of most gardens and lack of need for economic return as in commercial production. The primary weed control methods to be used by gardeners can be classified as cultural, mechanical, physical, and chemical. The University of California encourages gardeners to manage weeds using an integrated pest management (IPM) strategy. A central concept in IPM is integrating multiple control methods for long-term management of weeds with minimum impact on human health, the environment, and nontarget organisms.

Nonchemical management methods

Cultural

Cultural methods of weed control modify the immediate environment, improving the crop's competitive advantage and decreasing the weed's competitive edge. Cultural control methods include proper soil preparation, soil testing (pH, salts, fertility levels, etc.), irrigation management, correct crop plant selection, crop rotation, proper mowing height, thatch control, and reduction of soil compaction. These practices are probably the most overlooked weed control methods, which helps to explain why so many weed problems exist. Good cultural control can account for 60 to 70% of the weed control in turf; soil preparation prior to planting and selection of a well-adapted cultivar are two very important cultural practices in the initial stages. See chapter 11, "Lawns," for further information on cultivar selection and proper lawn care.

Herbicides are not recommended for use in vegetable gardens because of the diversity of vegetables usually grown and the limited number of herbicides permitted to be used on different vegetables. Most gardeners should rely on cultural, mechanical, and physical controls for weeds. Cultivation should be shallow to avoid injuring vegetable roots and to avoid bringing additional weed seeds to the soil surface. Fast-growing vegetables can reduce weed problems through their shading. Vegetables such as squash, beans, pumpkins, cucumbers, tomatoes, potatoes, and melons provide good weed suppression as they grow. Other vegetables such as lettuce, carrots, peppers, greens, onions, broccoli, and radishes suppress weeds poorly. Using transplants instead of seed gets plants off to a quicker start, and the shade they produce reduces seed germination and growth.

Mechanical and physical

Mechanical and physical methods are some of the most common weed control methods used by home gardeners. Mechanical control methods include hoeing or cultivation, hand-pulling, rototilling or disking, and mowing or chopping. Physical controls use a physical barrier or heat to control weeds, such as mulches, weed mats, black plastic, and soil solarization. Mechanical controls work very well with annual weeds as long as the weeds are

cut at or below the soil line (crown) before they set seed. Perennial weeds often grow back from their roots and therefore require repeated treatments to starve the plant by exhausting its carbohydrate reserves. This may require several or more years of diligent weed control.

It is surprising that we have forgotten how easy it is to maintain an area free of weeds with a hoe and a small investment of time on a weekly basis. After most of the cool- or warm-season weeds have germinated in the top ½ inch of soil, and provided that weed seeds have not blown into the area, that area will remain relatively free from annual weeds as long as the soil is not disturbed.

Sprinkle, sprout, spade, and spray (or water, wait, then cultivate) is an underused method of weed control that can eliminate up to 95% of a weed seed population for a particular season, allowing a planting to become established that is nearly weed-free. Prepare the area to the finished grade then water to germinate weed seeds that will sprout at that time of year. After most have emerged, spray or hoe them out and allow them to die. Do not hoe or cultivate deeply, as this will bring buried weed seeds to the surface. Then water a second time and repeat the process. This will eliminate most of the weed seeds in the top ½ inch of soil, where most of the germination occurs. Disturb the soil as little as possible during planting, or a new crop of weed seeds will be brought to the top.

Mulch. A mulch is simply a layer of opaque material over the soil surface. Mulches exclude light from weed seeds, eliminating photosynthesis. Mulches may be inorganic (synthetic), such as plastic or rock over plastic, or organic, such as bark, straw, hay, rice hulls, or compost. If a material is mixed into the soil, it is no longer considered to be a mulch.

Organic mulches can be very effective for controlling annual weeds. The coarser the material, the deeper the mulch must be in order to prevent as much light as possible from filtering down to the soil. Organic mulches also cool the soil (table 8.6) and should not be placed against the stem or trunk of plants, as this might cause disease. The mulch should be 1 to 3 inches deep for finer materials, such as sawdust or grass clippings, and 3 to 6 inches deep for coarser materials, such as bark, straw, or shredded plant matter.

Inorganic mulches include commercial weed mats (weed block, weed barrier, or landscape fabrics) as well as polyethylene black plastic. Weed mats may be made of polyester, polypropylene, or a mixture of peat moss and cellulose. They can be expensive, but many will provide several years of weed control in a landscape bed.

Mulches work on two principles: blocking the sunlight required for the germination of some weed seeds, and providing a thick layer that prevents growing weeds from reaching the sunlight, which causes them to die of starvation. Use black plastic, not clear, for weed control in landscapes and gardens. Plastic mulches do not allow water to penetrate, so special irrigation procedures, such as drip irrigation below the plastic, must be employed. Also, black plastic can interfere with gas exchange below the soil, which encourages root diseases. If sprinkler irrigation is being used or if the mulch is expected to remain for more than a season (for instance, in a permanent landscape bed), a landscape fabric is preferred. The clear plastic used in the cultivation of strawberries and certain other agricultural crops and for solarization (see below) influences soil temperature and keeps fruit from

Table 8.6.

CHARACTERISTICS OF MULCHES

Mulch	Soil temperature change (°F)	Comments
clear plastic	+10	traps heat; no weed control
black plastic	+6	transfers heat; good weed control
brown paper mulch	–8	good weed control; biodegradable
organic mulches	–10	good weed control if applied thick enough (3–6 in)

Source: Adapted from ***Gardening Shortcuts*** 1974.

contacting the soil, but it does not provide weed control.

Besides providing effective weed control, mulches reduce surface evaporation and can raise or lower the soil temperature (see table 8.6). A bark or straw mulch may be more aesthetically pleasing than black plastic, but it lowers the soil temperature, which may slow plant growth, especially in the spring. When mulches are used, the soil stays moist longer, which means that irrigation schedules must be adjusted. The tendency to overwater may result in root rot development from *Phytophthora* or *Pythium* spp. fungi.

Soil solarization. Developed in Israel, soil solarization uses a clear polyethylene plastic 1 to 4 mil in thickness with all of the edges securely weighted down or covered with soil. The thickness is not critical; thinner plastic seems to be a little more effective but is more susceptible to tearing and disturbance by wind. Plastic treated with an ultraviolet light inhibitor is recommended because ordinary clear plastic that is not treated with UV inhibitor will disintegrate after about 4 weeks of solarization. The plastic must be left in place for 4 to 6 weeks during June, July, August, and possibly into September. The more hours with a temperature over 95°F, the better the weed control. The soil should be loosened, moist, and finished to grade before laying the plastic. Solarization controls many (but not all) weeds and also effectively controls certain soilborne diseases, such as Verticillium wilt, and provides partial control of nematodes. For further information on soil solarization, see the UC IPM Pest Note *Soil Solarization for Gardens and Landscape Management* (Stapleton et al. 2008).

Weed species susceptible to solarization include annual bluegrass, annual sowthistle, barnyardgrass, Bermuda buttercup, cheeseweed, chickweed, henbit, lambsquarters, prickly lettuce, pigweed, and shepherd's purse. Partially susceptible are bermudagrass, creeping woodsorrel, bindweed, crabgrass, purslane, and wild oats. Solarization produces little to no control of sweet clover, burclover, or filaree.

Biological

Biological control of weeds employs natural enemies, such as insects and diseases, that feed on or infect weed plants and seeds to reduce the weed population below the level of economic injury. Although this control strategy has appeal and can be effective when combined with other control methods, it is primarily used only in natural areas rather than in home landscapes and gardens. Nevertheless, master gardeners should know that there is ongoing research on biological control projects for such weeds as puncturevine and yellow starthistle.

Chemical control methods

Herbicides: The last resort

Herbicides are organic or inorganic chemicals that kill plants. They are applied as foliar sprays or dry granular applications, depending on the herbicide and formulation. If used properly, herbicides can be safe and very effective. Always follow label directions and obey all rules and regulations associated with herbicides. It is critical to investigate and diagnose the causes of weed problems and correct them if possible before applying herbicides. Weeds will take over an area if the planting is weak and not growing well. Changing a cultural practice (watering, fertilizer, etc.) may increase the vigor of desired turfgrasses, vegetables, or ornamental plants, making them more competitive and reducing weed problems and the need for herbicides. Unfortunately, not all weed species can be selectively controlled with herbicides.

A successful and safe weed control program that uses chemicals as a component is based on effective interactions among the herbicide used, the target weeds, and the environment. To select the proper herbicide and method of application, you must know whether the crop and weed are annual, biennial, or perennial; the growth stage of both (germinating seed,

Table 8.7.

PERSISTENCE OF SELECTED PREEMERGENT HERBICIDES

Chemical name	Trade name	Persistence (months)
oryzalin	Weed Stopper	6–10
pendimethalin	Scotts Halts	3–8
trifluralin	Preen Garden Weed Preventer, Treflan	3–12

Note: Herbicide persistence will depend on a number of factors including herbicide rate, soil texture, irrigation frequency, temperature, microorganisms in the soil, soil pH, organic matter content, and sunlight.

seedling, or established plant); and the growth habit of both (deep or shallow root system, upright or horizontal leaves, etc.). Because of the toxic nature of herbicides and other pesticides, devote special attention to their proper use and understand weed susceptibility, crop tolerance, and pesticide safety.

For further information on pesticide labeling, types of pesticides, modes of action, application methods, formulations, additives, legal requirements, prevention of pesticide poisoning, protective equipment and clothing, application equipment, calibration of sprayers and spray patterns, storage and disposal, and environmental concerns, see chapter 9, "Safe and Sustainable Pest Management." For current, comprehensive information on herbicide use, see the UC IPM Online Weed Pest Management, ipm.ucdavis.edu/PMG/menu.weeds.html.

Just as the environment has profound effects on the interactions among crops and disease pathogens, it also influences the interaction among crops, weeds, and herbicides. Soil type, soil microflora, available water, temperature, and sunlight can affect the efficacy and environmental fate of herbicides. Herbicide labels often provide recommendations on the best environmental conditions for maximizing weed control and crop safety. Labels also warn about environmental conditions that should be avoided to minimize herbicide contamination of surface water and groundwater, herbicide drift, and poor efficacy.

Herbicide terminology

Preemergent versus postemergent. An herbicide application is preemergent if it is made before the weed seeds germinate. Preemergents are also referred to as soil-residual herbicides because they prevent germination of weed seeds or inhibit young seedling growth for a period of time. All preemergent herbicides must be moved into the germination zone in the soil, or activated, by mechanical incorporation, rainfall, or irrigation. The control provided by soil-residual herbicides may last from several weeks up to a number of years, depending on the particular chemical, rate used, and soil characteristics. Certain preemergent herbicides require activation within 24 hours, whereas others can wait up to 7 days and still others, up to 21 days. Consult the pesticide label for more information. The persistence of selected preemergent herbicides is given in table 8.7.

Postemergent applications are made to the weed foliage and require a period free of overhead watering of 1 to 24 hours, depending on the chemical. Postemergent application must be applied to living, emerged plants to be effective. Most do not have any soil activity. Postemergent herbicides include 2,4-D (Weed-B-Gon); diquat dibromide; fluazifop (Grass-B-Gon); glyphosate (Roundup); MCPP; fatty acid soaps (Herbicidal Soap); and triclopyr (Brush-B-Gon, Turflon).

Contact versus systemic. Foliar-applied herbicides can be contact or systemic. A chemical that kills only those parts of the plant it touches is a contact herbicide. If enough of the plant or the growing point is killed, the plant dies. Diquat dibromide, plant oil types (clove oil, vinegar), and petroleum distillates are examples of contact herbicides. Seedling annual weeds may be controlled with contact herbicides, but good coverage is important. Contact herbicides are most effective on younger plants.

A systemic herbicide is absorbed into the plant and moves through the plant's

conductive tissues by translocation. Foliar-applied systemic herbicides move from the treated leaves to other plant parts and may have their greatest effect at these distant sites. Control of established perennial weeds is best accomplished using a systemic herbicide, sometimes with repeat treatments. Glyphosate, fluazifop, and 2,4-D are examples of systemic herbicides.

Selective versus nonselective. Nonselective herbicides should be used when all vegetation is to be killed; selective herbicides should be used when certain specific weeds are to be killed without injuring desirable plants. The uninjured crop plants are said to be tolerant of the selective herbicide, and the weed species is said to be susceptible. In general, contact herbicides are nonselective, and systemic herbicides may be either nonselective or selective. Combinations of the terms can be used to describe individual herbicides:

- glyphosate (Roundup): postemergent, systemic, nonselective
- 2,4-D: postemergent, systemic, selective
- benefin and oryzalin (Amaze): preemergent, selective
- dithiopyr (Crabgrass Preventer): preemergent, selective

Selecting the Best Herbicide

Selecting the best herbicide is often more difficult than selecting insecticides or fungicides. Deciding which herbicide to use requires knowledge of the characteristics of the herbicides under consideration, the environment (soil characteristics and climate), and the weed-crop complex, specifically, which weeds are to be controlled in which landscape or crop. Several questions must be considered:

- What weed species are to be controlled? What are their life cycles and growing seasons?
- Are the weeds present in a noncrop area, turf, or ornamental site?
- Is the herbicide registered for the intended application (site, plants)?
- What are the soil characteristics (sandy, loamy, clayey)?
- What are the environmental conditions (temperature, rainfall, soil moisture, sunlight)?
- What type of herbicide application equipment is available?
- What is the desired duration of weed control?
- If a preemergent herbicide has been selected, how and when will it be irrigated or incorporated into the soil?
- Given the complexity of these decisions, would it be easier to remove the weeds by hand?

Herbicide Application Methods

Proper application methods are essential to successful herbicide treatments (see chapter 9, "Safe and Sustainable Pest Management," for more information). Herbicides must be applied uniformly and at the labeled rate over the area to be treated. Herbicides can be applied using push or handheld spreaders (granules), hand-operated compressed-air pumps (backpack sprayers), or power sprayers. Read the herbicide label for recommended application methods and follow them. An even travel speed (walking or driving), proper nozzles, correct spray height, and required nozzle spacing must be monitored and maintained to ensure uniform application. Backpack sprayers are most effective in small areas and for scattered weed patches. Poor application techniques can easily result in too little or too much herbicide being applied over a given area. Spray equipment must be calibrated accurately if liquid herbicides are to be used safely and effectively.

Rates for preemergent herbicides are generally given in ounces or fluid ounces per 1,000 square feet in sufficient amounts of water to give uniform coverage. The rate essentially refers to spreading a specified amount of herbicide over a particular area. Water is often the liquid vehicle to help spread a preemergent herbicide evenly. Control might be achieved by using 2¼ gallons of water per 1,000 square feet or by using 1 gallon of

Example Calculation for an Herbicide Application

Oryzalin is a preemergent selective herbicide with label rates of 1.5 to 3 fluid ounces per 1,000 square feet in selected ornamentals. The lower rate is for short-term control (3 mos) and the higher rate is for longer-term control (6–9 mos). Assume that you want to cover 3,000 square feet and you have a 4-gallon backpack sprayer. How do you determine how much herbicide and water to use in the sprayer?

To find the volume of oryzalin to be applied for short-term control, multiply the rate of herbicide by the number of thousands of square feet to be covered:

$$1.5 \times 3 = 4.5 \text{ fluid ounces}$$

The volume of water to be used is listed on the label as a given range. For oryzalin, this range is 1.25 to 2.5 gallons of water for each 1,000 square feet sprayed, depending on the size of the weeds. In this example, we will choose the lowest volume in the range. We would use

$$1.25 \times 3 = 3.75 \text{ gallons of water}$$

to cover 3,000 square feet. Therefore, we would add 4.5 fluid ounces of oryzalin to 3.75 gallons of water in the backpack sprayer for this application. For more information, see the Purdue University Extension publication *Pesticide Safety and Calibration Math for the Homeowner* (Whitford and Martin 2003).

water per 1,000 square feet. For larger areas, this would be 100 or 50 gallons per acre, respectively.

Premixed granular and liquid ready-to-use formulations are preferred for home gardeners. This eliminates most calculation errors, uses less-complex application equipment, and eliminates mixing with water and disposal of wastes. Granular herbicides are often sold premixed with fertilizers, generally for use on turf. Such formulations are not the best choice for homeowners, since the timing for fertilizing and weed control can differ. These mixtures are not suitable or even labeled for vegetables because of the risk of injury to vegetables.

Weed Susceptibility to Chemical and Nonchemical Methods

Herbicides are not a cure-all for every weed problem. Selective herbicides are selective not only for protecting the ornamental or vegetable plant you are trying to grow but also for the weeds they control. For example, weeds such as spotted spurge, henbit, and burclover are controlled by only a few preemergent herbicides. Nonselective herbicides will not necessarily control all weeds in an area. For example, although glyphosate is nonselective, it does not control mature weeds of certain species, such as malva, filaree, and nettle. To get an idea of the differences between the weeds that various herbicides control, refer to the commercial turf pest management guideline section "Susceptibility of Weeds to Herbicide Control," at the UC IPM website, ipm.ucdavis.edu/PMG/r785700911.html.

It is highly desirable to identify the weed species in question when recommending or using chemical or nonchemical controls. Refer to the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden, for the specific weed when attempting to find a control for a weed problem. For a current list of recommended herbicides for individual weeds, see the UC IPM Pest Notes for Weeds, ipm.ucdavis.edu/PMG/menu.weeds.html. Also see the section "Common Garden Weeds in California and Recommended Controls" at the end of this chapter.

Turf Weed Management Checklist

A healthy lawn will crowd out many weed problems. Weedy turf often results from a breakdown in the turf management program. For details on proper turf management practices see chapter 11, "Lawns," and the "UC Guide to Healthy Lawns" at ipm.ucdavis.edu/TOOLS/TURF/. The following management actions encourage a weed-free, healthy lawn:

Proper irrigation management, including the amount, frequency, uniformity, and time of day of watering. Overwatering and frequent watering encourage seedlings of crabgrass and other annuals. Underwatering turf-

grasses stresses the turf, giving drought-tolerant broadleaf weeds such as clover or knotweed a competitive edge.

Evaluation and correction of problems associated with soil pH, salt level, and water infiltration.

Proper application of selected fertilizers. Fertilizing at times or rates not conducive to the turf can encourage weeds. Turf needs adequate fertilizer to outcompete weeds.

Thatch more than ½ inch thick interferes with water infiltration and can increase stress in the turf.

Correct mowing height for a particular turf species. Summer weeds tend to gain a competitive edge if cool-season turfgrasses are mowed too short (below 1½–2 in). For example, Kentucky bluegrass mowed, too closely, at ½ inch may contain twice as much annual bluegrass than if mowed at 1½ inches.

Species of turfgrass selected. Turf-type tall fescues generally have fewer weed problems than bluegrass-ryegrass mixtures and bermuda lawns because they are mowed higher and the plants shade more, excluding light to weeds and seeds. However, it is essential to choose a turf species that grows vigorously in your location and under the local conditions (shade, soil type, drainage, climate) in your landscape.

Prevent weeds from producing seed by mowing flowers or removing weeds before they mature.

Ornamental Weed Management Checklist

Many of the same considerations that apply to turf also apply to landscape ornamentals. Some additional considerations include the following:

When used properly, mulches are very effective in controlling weeds. But an organic mulch, landscape fabric with bark mulch on top, or even a stone mulch may have some weeds growing in it. Occasional pulling will control these weeds.

Several herbicides can be used in ornamentals that are not available for use in turf, and vice versa. However, drift of herbicides onto adjacent susceptible ornamentals is a frequent cause of damage to the landscape. Always read and follow the label directions to avoid problems.

Certain ground cover plants such as gazania and *Arctotheca* spp. establish fast and have few weed problems. Ivy and vinca establish slowly and require more weeding.

Vegetable Garden Weed Management

Herbicides are not generally recommended in vegetable gardens. A few herbicides are registered for use with certain vegetables, but because gardens usually contain a mixture of crop species, it is too difficult to make applications to only one species. Mechanical and cultural techniques, including mulches, hoeing, solarization, and the sprinkle, sprout, spray, and spade method discussed earlier are recommended for managing weeds in vegetable gardens. See chapter 13, "Home Vegetable Gardening," for more information.

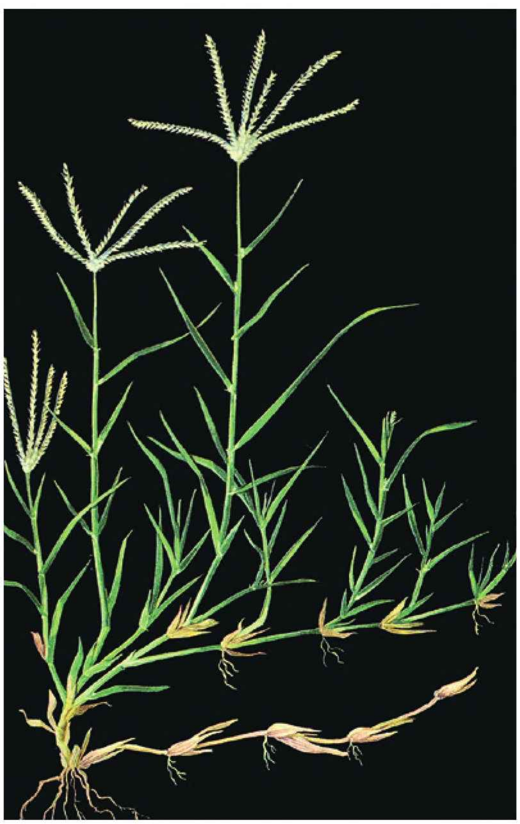
Common Garden Weeds in California and Recommended Controls

For a current list of approved preemergent and postemergent herbicides, see the Weed Research and Information Center's weed susceptibility chart at wric.ucdavis.edu or the IPM Pest Notes for individual weeds at ipm.ucdavis.edu/PMG. Apply herbicides only at the labeled rate and only for labeled weeds; follow all label directions.

COMMON GARDEN WEEDS OF CALIFORNIA

***Bellis perennis* L. (English daisy)**
Perennial. Low growing, with oval basal leaves; white or pink flowers. *Photo:* J. M. DiTomaso
Control: Apply postemergent herbicide; rogue or dig out plants.

***Convolvulus arvensis* (field bindweed)**
Perennial. Very deep rooted, 6 to 10 feet; twining stems; white or pink flowers are similar to morningglory. *Photo:* J. M. DiTomaso
Control: Cultivate repeatedly to starve roots over 1 to 2 years. Apply postemergent herbicide.



***Cynodon dactylon* L. (bermudagrass)**
Perennial, prostrate; spreading. Has rhizomes and stolons; leaves have a conspicuous tuft of hair at base; does not grow well in shade; often used as a lawn. *Photo:* ANR
Control: Raise mowing height to greater than $1\frac{1}{2}$ inch in cool-season turf.

***Cyperus esculentus* (yellow nutsedge)**
Perennial (dormant in winter). Spreads by seed and tubers; in sedge (not grass) family; leaves are stiff and upright; nutlets have almond taste. One plant can make 400 new tubers in 1 year. *Photo:* J. M. DiTomaso
Control: Remove plants frequently to starve nutlets. Apply postemergent herbicide.

***Oxalis corniculata* L. (creeping woodsorrel)**
Perennial with running rootstocks. Prefers shade. Leaves resemble those of clover; sour taste; seed ejected 10 to 13 feet. *Photo:* J. M. DiTomaso
Control: Encourage healthy turf; fertilize and water properly. Apply preemergent or postemergent herbicides.

COMMON GARDEN WEEDS OF CALIFORNIA cont.

***Paspalum dilatatum* (dallisgrass)**
Perennial; bunch-type growth from a spreading crown. Rhizomes are very closely jointed; seed heads are sparsely branched. Plant goes dormant in winter. *Photo:* J. M. DiTomaso
Control: Remove established clumps with shovel or apply postemergent herbicide. Apply preemergent herbicide in February or March.

***Pennisetum clandestinum* (kikuyugrass)**
Perennial; prostrate. Very thick rhizomes and stolons; similar to bermudagrass except coarser. Frequently mistaken for St Augustinegrass. *Photo:* J. M. DiTomaso
Control: Difficult to control, even with preemergent or post-emergent herbicide.

***Rumex crispus* L. (curly dock)**
Perennial. Grows from a large, thick taproot; wavy leaves grow from a rosette. *Photo:* J. M. DiTomaso
Control: Remove taproot; apply postemergent herbicides.

***Taraxacum officinale* (dandelion)**
Perennial. Grows from a large, thick taproot. *Photo:* J. M. DiTomaso
Control: Mow frequently. Apply postemergent herbicide. If pulling or hoeing, remove all pieces of taproot.

***Digitaria* spp. (crabgrass)**
Summer annual; spreads and roots at nodes. Two main species, one hairy (large) and the other smooth. Both green to yellow green; a problem especially in overwatered turf. *Photo:* C. Elmore
Control: Water deeply and less frequently. Apply preemergent herbicide in February or March.

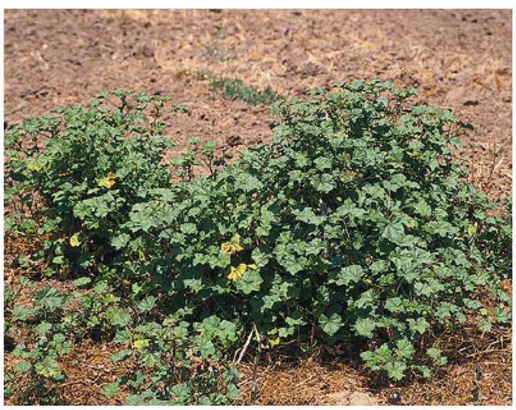
***Euphorbia maculata* (spotted spurge)**
Summer annual. Has milky sap in leaves with red spots in upper center of leaf. *Photo:* C. Elmore
Control: Mulch; mow at recommended height. Apply preemergent and/or postemergent herbicide.

***Hordeum leporinum* (wild barley)**
Winter annual; bunchgrass. Dull green, smooth leaves; a problem in newly seeded turf. *Photo:* J. M. DiTomaso
Control: Mulch and hoe to prevent seed formation. Apply preemergent herbicide in September.

COMMON GARDEN WEEDS OF CALIFORNIA cont.

***Lolium multiflorum* (Italian ryegrass)**
Winter annual; bunchgrass. Glossy appearance; seed stalks are long with spikelets attached on alternate sides. *Photo:* J. M. DiTomaso
Control: Hoe and mulch; apply preemergent herbicide in September.

***Polygonum arenastrum* (knotweed)**
Summer annual. Forms a circular mat. Can grow in compacted, droughty soil. *Photo:* J. M. DiTomaso
Control: Encourage healthy turf; fertilize and water properly.



***Malva parviflora* (little mallow)**
Winter annual or biannual. Leaves are large and rounded with red spots at base of the blade. Common in poorly managed turf. *Photo:* J. M. DiTomaso
Control: Encourage healthy turf. Apply preemergent or postemergent herbicide.

***Setaria glauca* (yellow foxtail)**
Summer annual; bunchgrass. Leaves are flat, some with a spiral twist; spikes are dense and erect; spikelets have five or more slender bristles. *Photo:* J. K. Clark
Control: Mulch and hoe. Apply preemergent herbicide after February.

***Poa annua* L. (annual bluegrass)**
Winter annual; bunchgrass. Tufted, light green, usually found in cool, frequently watered areas. Seed continue to form even if mowed as low as ¼ inch. *Photo:* J. M. DiTomaso
Control: Reduce soil compaction; improve water drainage. Water less frequently. Hoe or rogue plants and apply mulch. Apply preemergent herbicide in September.

COMMON GARDEN WEEDS OF CALIFORNIA cont.

Picris echioides L. (bristly oxtongue)
Biennial; mostly prostrate. Leaves 2 to 6 inches long; rough and hairy on upper and lower surfaces; yellow flower heads. *Photo:* J. M. DiTomaso
Control: Mulch and hoe. Difficult to control effectively with preemergent or postemergent herbicides.

Plantago spp. (plantain)
Two species, both perennial. Seed stalks of buckhorn are much longer than common broadleaf. *Photo:* J. M. DiTomaso
Control: Hoe or pull plants; mulch; apply postemergent, selective herbicides in turf.

Portulaca oleracea (purslane)
Summer annual; prostrate. Very fleshy stems and leaves; pale yellow flowers; an edible plant. *Photo:* J. M. DiTomaso
Control: Hoe or pull plants (turn plants upside down so they don't reroot).

Stellaria media L. (chickweed)
Winter annual. Many-branched stems; opposite, pointed leaves. *Photo:* J. M. DiTomaso
Control: Encourage healthy turf. Mow at proper height. Hand-pull or hoe plants.

Veronica persica L. (birdseye, Persian speedwell)
Winter annual; stems 4 to 16 inches long. Roundish leaves and small blue flowers with white centers; covered with hairs. *Photo:* J. M. DiTomaso
Control: Mulch and hoe. Apply preemergent herbicide.

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Safe and Sustainable Pest Management

9

Julie P. Newman and
Richard H. Molinar

Learning Objectives

Learn the principles of integrated pest management.

Learn the basic rules for successful pest management.

Recognize the preventive pest control methods available to home gardeners.

Recognize the nonchemical pest control methods available to home gardeners.

Understand how pesticides are categorized and be familiar with common pesticide formulations.

Recognize differences between home garden and commercial-use pesticides.

Learn how to read and understand pesticide labels.

Learn how to use pesticides safely, how to avoid pesticide poisoning, how to recognize pesticide poisoning symptoms, and what to do when injury occurs.

Become acquainted with legal issues associated with home gardeners' uses of pesticides.

Learn about pesticide mixing, application equipment, calibration, and pesticide storage and disposal.

Learn how to protect nontarget organisms and the environment from pesticides.

Safe and Sustainable Pest Management

An important role of master gardeners is to extend to the public University of California (UC) research-based information about pest management in homes and gardens. This includes diagnosing plant problems and selecting appropriate control actions for pests when applicable. In order for master gardeners to assist others in choosing pest management practices that are safe and effective, it is important that they understand the concepts of integrated pest management (IPM).

IPM is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of management methods. These methods vary in their effectiveness, depending on the pest, differences in plant growth and productivity, pest damage, weather conditions, and cultural practices. Therefore, a combination of several methods is usually more effective than any single control method in minimizing pest damage.

Home gardeners can choose from an array of methods to eliminate or reduce pest problems. Nonchemical methods such as cultural practices, mechanical barriers, and the use of biological controls are safe and effective ways for people to manage many pests in their gardens. Ideally, pesticides should be used only when careful monitoring indicates they are needed, as a last resort to augment nonchemical pest management practices. The least-toxic and most target-specific pesticides should then be selected. IPM programs can be carried out in most gardens with almost no use of pesticides that are more toxic than soaps, horticultural oils, or microbials.

The University of California encourages gardeners to select sustainable pest management practices that provide long-term prevention or suppression of pest problems with minimum impact on human health, the environment, and nontarget organisms. IPM programs prevent pest damage or keep pests at tolerable levels by using knowledge about the pests and what encourages or discourages them in the garden. The most important benefit of an IPM program is more precise and effective pest management.

A better understanding of pests in the garden, together with frequent monitoring for pests, allows gardeners to maximize their control efforts. Monitoring is the backbone of any IPM program. Monitoring can eliminate unnecessary pesticide applications and has the advantages of cost savings and reduced risk to health and the environment. For example, gardeners should regularly inspect plants for insects and for signs of insect activity before implementing a control action for pests. A hand lens (10–15×) is an important tool for gardeners because many of the pests that must be monitored in gardens are tiny. Other monitoring tools, such as yellow sticky cards for adult flying insects or tape for scale insects, can also be useful for monitoring insects. Repeated application of pesticides frequently leads to the development of strains of pests resistant to the pesticides that once controlled them. Minimizing pesticide use through an IPM program should limit the development of pesticide resistance.

Principal components of an IPM program are

- pest identification
- methods for detecting, monitoring, and predicting pest outbreaks
- knowledge of the biology of pests and their ecological interactions with hosts, natural enemies, and competitors
- ecologically sound management methods of preventing or controlling pests

Preferred management techniques in an IPM program include

- encouraging naturally occurring biological controls
- using alternative plant species or varieties that resist pests, or using stock that has been certified as pest-free
- selecting pesticides with lower toxicity to humans and nontarget organisms
- adopting cultivation, pruning, fertilization, and irrigation practices that reduce pest problems
- changing the habitat to make it incompatible with pest development

An effective IPM program requires a well-trained and informed decision maker. See *Pests of the Garden and Small Farm* (Flint 1998), *Pests of Landscape Trees and Shrubs* (Driestadt 2004), the UC IPM Pest Notes (ipm.ucdavis.edu/homegarden), and UC IPM Pest Management Guidelines (ipm.ucdavis.edu) for general overviews of designing pest management programs, monitoring recommendations, and IPM programs for specific pest problems.

Rules for Successful Pest Management

In helping other people identify and control pest problems, master gardeners should keep in mind three basic rules for successful pest management: identify the problem and whether a control action for pests is warranted; select a proper control action strategy; and evaluate the results of the control action(s) and develop a pest management plan.

First Rule: Identify the Problem and Whether a Control Action Is Warranted

A basic IPM precept is that before a pest can be managed, the problem must be identified. Proper identification of the underlying cause(s) of poor plant performance is essential in making appropriate and effective IPM decisions. Pesticides and other control actions that may be effective for a given pest may not be appropriate for another pest. In addition, poor plant growth and damage is not always caused by pests. Sometimes these problems are due to environmental and cultural conditions such as unfavorable temperatures, insufficient light, or overwatering. Symptoms related to environmental conditions or to nutrient or water stress cannot be remedied with pesticides. If problems are incorrectly diagnosed, inappropriate chemical treatments could be used that will be ineffective and add unnecessary pesticide loads to the environment. Master gardeners should refer to chapter 21, "Diagnosing Plant Problems," and appropriate sections in chapters 6, "Plant Pathology," and 7, "Insects," for techniques used in proper plant problem diagnosis.

Solving the problem entails much more than just identifying the pest in question. It also requires knowing the different stages of the pest and the pest's life cycle. This information is crucial to understanding whether a control action is warranted and what its optimal timing would be. In many cases, problems are brought to a master gardener when it is already too late to take effective action that year. For example, homeowners frequently call UC Cooperative Extension after their oak trees are defoliated by the California oakworm, wanting some recommendation to control the pest. When the last pest generation is already pupating, there is nothing that can really be done: it does little good to control mature caterpillars that have already done their damage.

In deciding whether a control action is necessary, also keep in mind that people vary greatly in what they perceive to be a problem. For example, some gardeners who grow roses to be displayed in county fairs may perceive mildew to be a significant problem requiring action at the first sign of disease, or even earlier as a preventive measure; others may tolerate mildew and choose to do nothing.

Second Rule: Select a Proper Control Action Strategy

The choice of control actions for pests is often quite broad and should be guided by safety to the environment and to all people involved. The best management strategy will often be using a combination of appropriate methods and following an IPM approach to managing the pest. People vary greatly in the kind of pest control they would consider implementing. Some people never apply pesticides under any circumstance and would prefer to handpick pests, grow other plant species, or use biological control. Others may use pesticides, but would select only those such as insecticidal soaps, oils, or microbials that present little or no health risk.

When several effective control options exist, master gardeners should offer all that are reasonable and approved by UC, including appropriate pesticides if available. Check for possible chemical control options with low toxicity to humans and nontarget organisms and offer this information to the client. Furthermore, if there are hazards associated with the use of chemical options listed in UC reference materials, such as hazards to bees or potential pesticide runoff hazards, communicate this information as well. Then, let the client make the choice.

All pesticide recommendations to the public must be recommendations published by UC. Do not recommend home remedies for use as pesticides unless UC has a published recommendation for the remedy. Refer to the UC IPM Pest Management Guidelines, ipm.ucdavis.edu, for current management options; refer to the section in "Landscape and Garden Pesticides," ipm.ucdavis.edu/PMG/menu.pesticides.html, for hazards associated with the use of common garden pesticides. Also see chapters 6, "Plant Pathology," 7, "Insects," and 8, "Weed Science," for management strategies to control specific pests.

Timing of control actions entails knowing the pest life cycle and its ecological interactions with hosts, natural enemies, and competitors. Select appropriate management strategies and apply them properly at the most vulnerable time in the life cycle of the pest or in a manner that affects the disease triangle. For example, the only vulnerable point in the life cycle of the juniper twig girdler is a brief period when the adult moths are active (March to May in southern California; June to mid-July in the Bay Area). During the rest of the year, the insect is tunneling beneath the bark and cannot be controlled by any known means.

Third Rule: Evaluate the Results of the Control Action(s) and Develop a Pest Management Plan

Monitoring is an important component of an IPM program, not only to identify pest problems but also to evaluate management measures. Monitoring for pests or diseased plants before and after a control action is applied is crucial to evaluating and refining the overall strategy. However, evaluating the effect of control actions in garden situations may be difficult unless untreated plants can be used to make comparisons. For example, if insect pests die after applying a pesticide, it is difficult to know whether this can be attributed to the applied pesticide or to a natural decline in the pest population due to other factors.

Master gardeners should assist clients not only with their current pest problems but also in developing a plan for managing future potential problems. Past experience with a pest problem helps refine future

strategies. The pest management plan should include preventive pest management practices (see the next section) such as planting at a different time; using alternative plant species or varieties that resist pests; using stock that is certified as being pest-free; and adopting cultivation, pruning, fertilization, and irrigation practices that reduce pest problems. For example, if a client has been constantly battling imported cabbage worm on spring-planted cabbage, growing the cabbage in the fall when this pest is less apt to be a problem is a preventive management option that could be offered to the client for the overall pest management plan. If a client has had significant problems with greenhouse whitefly on fuchsia (a favored host of this pest), planting another ornamental with fewer plant protection requirements is an option that the client could consider.

Prevention

Preventive management strategies are methods that prevent pest development and spread. These methods reduce pesticide use in the garden and pesticide loads in the environment. Prevention is the best control method and is critical to any IPM program. Preventive management strategies to avoid pest development and spread include using resistant plant varieties, good sanitary practices, and proper plant culture.

Planting Resistant Cultivars or Species

Cultivars or species that are resistant to pest activity, or at least tolerant of them, can be effective in reducing pest problems. Pest resistance in plants is frequently interpreted as meaning "immune to pest damage." Actually, it refers to plant varieties that exhibit less pest damage than do other varieties under similar growing and pest population conditions. Some varieties may be less desirable to pests or may possess physical or chemical properties that discourage pest feeding or inhibit pest growth and development or reproduction. Others may be able to support large pest populations without suffering appreciable damage. Before buying seeds or plants, check sources such as seed catalogs for information on resistant varieties that grow well in your area. Some varieties may be resistant to pest attack but may be subject to other restrictions such as soil pH, drainage, or temperature. Experience with different varieties will indicate the ones best suited for specific garden situations.

Sanitary Practices

Good sanitary practices, such as removing infested or dead plants, reduce reservoirs of pests and pathogens that may infect garden plants. For example, removal and disposal of disease-infected limbs or other parts of perennial plants is an effective means of reducing or controlling certain diseases such as fire blight. Weeds are sometimes hosts of insects that can vector plant diseases. Keep weeds in check before they produce seed to reduce future infestations.

Proper Cultural Practices

Many pest problems can be prevented by providing good growing conditions to avoid environmental stresses. Healthy plants are more likely to avoid or withstand infection or infestation by pests than are unhealthy plants. Gardens have numerous microenvironments, small areas that differ in temperature, humidity, and light. Sites should be selected within the garden that best match specific plant requirements.

Maintain vigorous growth by providing plants with the proper fertilization, irrigation, and other cultural practices that are optimal for the species. When properly used, fertilizers and water promote healthy plant growth and increase the capability of plants to tolerate pest damage. However, excessive amounts of compost or manure can encourage millipedes, pillbugs, white grubs, and other

pests. Improperly prepared composts can introduce pests or may possess chemical characteristics unsuitable for some plants. Similarly, overwatering can encourage development of stem and root diseases.

Nonchemical Control Options

A fundamental concept of IPM is that a limited amount of pest damage to plants can be tolerated. Produce from the home garden does not have to live up to the near-perfect appearance of market standards. If the choice is between minor insect damage and a pesticide application, home gardeners must be willing to sacrifice a few plants and accept some visible blemishes to plants, fruits, and vegetables. Many home gardeners use nonchemical pest control methods, and an increasing number are choosing not to use pesticides. Good garden practices combined with nonchemical control help reduce losses from pests and the need for pesticides. Nonchemical control options include cultural control, mechanical control, environmental control, and biological control.

Cultural Control

Cultural controls are modifications of normal plant care activities that reduce or prevent pests. Knowledge of the life histories of pest species is essential to the effective use of cultural control methods. Since these methods are used more to prevent pest problems than to control them, some of these methods were discussed in the "Prevention" section, above. Other cultural control methods include digging, tilling and cultivating; crop rotation; changes in planting or harvesting times; and garden diversification.

Digging, tilling, and cultivating. Digging, tilling and cultivating can effectively reduce or eliminate weeds in the garden and expose soilborne pests to adverse environmental conditions or predators. In addition, deep digging buries some insects and prevents their emergence.

Crop rotation. Rotating vegetable crops in the garden can be effective against diseases and insect pests that develop on a particular family or genus of plants, especially if these pests have short migration ranges, such as soilborne insects and pathogens. Moving crops to different sites isolates these pests from their food sources. If an alternative site is not available, change the sequence of plants grown in the garden plot. Do not plant members of the same plant family in the same location in consecutive seasons; for example, do not follow melons with cucumbers or squash.

Changes in planting or harvesting time. Planting and harvesting at specific times often reduces plant damage or keeps pests separated from susceptible stages of the host plant. For example, seed maggot damage and damping-off can be reduced by delaying planting until the soil is warm enough for corn and bean seeds to germinate quickly.

Garden diversification. An orderly mixing of crop plants (intercropping) is aimed at diversifying host plant populations to reduce pest problems. In some cases, adding certain flowering plants to a garden can increase floral and nectar sources for beneficial insects that provide biological control of pest insects. Numerous claims have been made about the ability of certain plants to protect certain other plants from pest damage (companion planting). However, these claims are not substantiated by data from scientific studies.

Mechanical Control

Mechanical controls reduce insects, weeds, or diseases by using labor such as hand-picking or devices such as traps or barriers that exclude pests.

Preventive mechanical devices. Preventive mechanical devices that exclude pests are often easy to use, although their effectiveness varies. Such devices include

- paper collars around the stems of plants or the trunks of woody plants to prevent damage from pests such as cutworms, rodents, and rabbits (fig. 9.1).

cheesecloth screens for hot beds and cold frames to prevent insect egg-laying

mesh covers for small fruit trees, berry bushes, tomatoes, and other plants to keep out large insects and birds

sticky barriers on the trunks of trees and woody shrubs to prevent damage by crawling insects and other pests

reflective plastic mulches on the soil beneath rows of plants and the use of reflective mesh plant covers to repel aphids and other insects

coarse organic mulches, black plastic mulches, and landscape fabrics to exclude weeds in landscapes and gardens

Hand-picking, hand-pulling, and hoeing. Hand-picking of insects and insect egg masses ensures quick and effective control. This method is especially effective with foliage-feeding pests such as bean beetles, potato beetles, hornworms, squash bugs, and snails. Weeds can often be managed by hand-pulling or hoeing.

Washing. A fine stream of water under pressure can sometimes dislodge pests from stems and leaves on plants that are sturdy enough to withstand the pressure. For example, spider mites can be physically controlled by washing them off leaves. This technique also increases humidity around leaves, which may help to bring spider mite infestations under control but may also encourage foliar disease problems. The use of a strong stream of water directed to the underside of infested leaves can be very effective in managing giant whitefly. Comparison studies with several pesticides indicate that washing performed as well as or better than chemical treatments.

Traps. Various types of traps are reportedly successful in reducing pest numbers:

Earwigs can be trapped in a low-sided can sunk into the ground and filled with vegetable oil and a drop of bacon grease or tuna fish oil; rolled-up newspapers placed in the garden or other locations where these insects gather can also be used as traps.

Slugs and snails can be trapped in a small pan placed flush with the soil and filled with stale beer; a mixture of sugar water and yeast can be substituted for the beer. Boards and melon rinds also can be used as traps.

Figure 9.1

Paper tree protectors are mechanical devices that can be used to exclude certain pests and prevent damage from rodents and rabbits. *Photo:* J. K. Clark

Environmental Control

Environmental (physical) control methods include using light and temperature and other environmental manipulation methods to control certain insects and pathogens.

Light traps. Black-light traps are effective tools for monitoring insect species but usually provide little control. Light traps attract harmful and beneficial insects that ordinarily would not be found in the area. Insects may not be caught in the traps but may remain in the area, and the harmful ones may cause damage later. Some species (wingless insects and insects active only during the day) are not caught in the traps. Consequently, the value of black-light traps in the home garden is questionable. Where black-light traps are used, they should be placed 50 to 75 feet away from the area to be protected.

Keeping foliage dry. Keeping foliage dry by eliminating overhead irrigation can reduce or control some bacterial and fungal foliar diseases, such as black spot of rose.

Hot water dips. Soaking flower bulbs in hot water (140°–150°F) can effectively control certain bulb pests in home gardens.

Heat pasteurization of growing media. Small quantities of potting mix can be pasteurized in a conventional or microwave oven. Moisten the potting mix and allow it to bake at 180° to 200°F for about an hour in a conventional oven. To treat potting mix in the microwave, moisten it and place it in a plastic bag. Heat the potting mix long enough so that it reaches 180°F (about 10–15 min). With either method, insert a temperature probe into the potting mix to be sure it has heated to a minimum of 180°F. Once the potting mix cools, it is ready to use or store for future use.

Composting. Composting is another heat treatment that is used to control soilborne pests. See chapter 3, "Soil and Fertilizer Management," for details.

Soil solarization. Soil solarization can be used as a heat treatment to control weed pests. See chapter 8, "Weed Science," for details.

Biological Control

Pests can be managed by biological control, using beneficial organisms such as insects that eat or parasitize other insects. This section provides some basic concepts on biological control. It includes information that can be used to identify common beneficial organisms found in California gardens and implement practices that encourage them. Master gardeners can further increase their knowledge of biological control concepts and management techniques appropriate to home gardens by consulting the biological control resources provided on the UC IPM Pest Management Guidelines website at ipm.ucdavis.edu/PMG/menu.biocontrol.html.

Concepts and terminology

Biological control can be defined broadly as any activity of one species that reduces the adverse effect of another. Species that provide biological control of pests are often called beneficials or biological control agents because they help to keep pest populations low enough to prevent significant economic damage. Naturally occurring biological control agents of pests include pathogens, parasitoids, predators, competitive species, and antagonistic organisms.

Pathogens are microscopic organisms, such as bacteria, viruses, and fungi, that cause diseases in pest insects, mites, nematodes, or weeds. In a few cases, methods of introducing diseases into pest populations have been developed.

Parasitoids attack host insect pests, such as aphids, scales, whiteflies, and cutworms, and spend part or all of their life cycle with their host. Parasitoids are generally tiny wasps or flies that use their ovipositor (stinger) to deposit one or more eggs in or on a single host. When the eggs of the parasitoid hatch, the larvae feed on or inside the host. Eventually the host dies and an adult parasitoid emerges, often leaving behind the dried body of the host—such as an aphid mummy—with a distinct exit hole where the parasitoid chewed its way out (fig. 9.2). Parasitoids are often described in terms of the host stage within which they develop. For example, there are egg parasitoids, larval parasitoids, larval-pupal parasitoids, pupal parasitoids, and a few species that parasitize adult insects.

Predators are generally very mobile and, unlike parasitoids, are usually larger than their prey (the pest species). Predators include a wide range of beneficial insects (fig. 9.3), spiders, mites, and many other living organisms. A predator seizes, overpowers, or immobilizes its prey, then either consumes it entirely or sucks its body fluids. Larval stages and, frequently, adult stages feed on prey. General preda-

tors that feed on a wide variety of pest species are very important in gardens.

Competitors in a home orchard or vegetable garden include cover crops, which are plants such as grasses and legumes that have been selected and managed to serve as living mulches and outcompete pest weeds. Competitors also include nonpathogenic soil-dwelling fungi that compete for resources and reduce or exclude populations of plant-pathogenic fungi.

Antagonists are species that release toxins or otherwise change environmental conditions so that pest activities or populations are reduced. For example, naturally occurring soil fungi and bacteria may antagonize nematodes by producing compounds that are toxic to them.

Many beneficial organisms occur naturally around the garden and are at work controlling pest populations without any assistance from the gardener. The importance of biological control agents may not be appreciated until a broad-spectrum pesticide that kills certain natural enemies as well as targeted pests is applied and a new pest—suddenly released from biological control—becomes a serious problem. This phenomenon, known as a secondary pest outbreak, occasionally occurs in gardens. One example might be the sudden outbreak of aphid, scale, mite, or whitefly populations throughout a garden soon after a large tree has been sprayed with a broad-spectrum insecticide such as carbaryl. Not only are the pest insects in the tree destroyed, but the insect parasitoids and other natural enemies in, beneath, and adjacent to the tree canopy are killed as well. The relationships among the host, pest, and natural enemy make it impossible to have a pest-free environment and at the same time maintain sizable populations of beneficial species.

In addition to naturally occurring biological control agents, weather conditions influence pest populations. In some years, pests may not be numerous enough to damage plants significantly; in other years, large populations may cause serious damage or completely destroy host plants.

Biological control methods

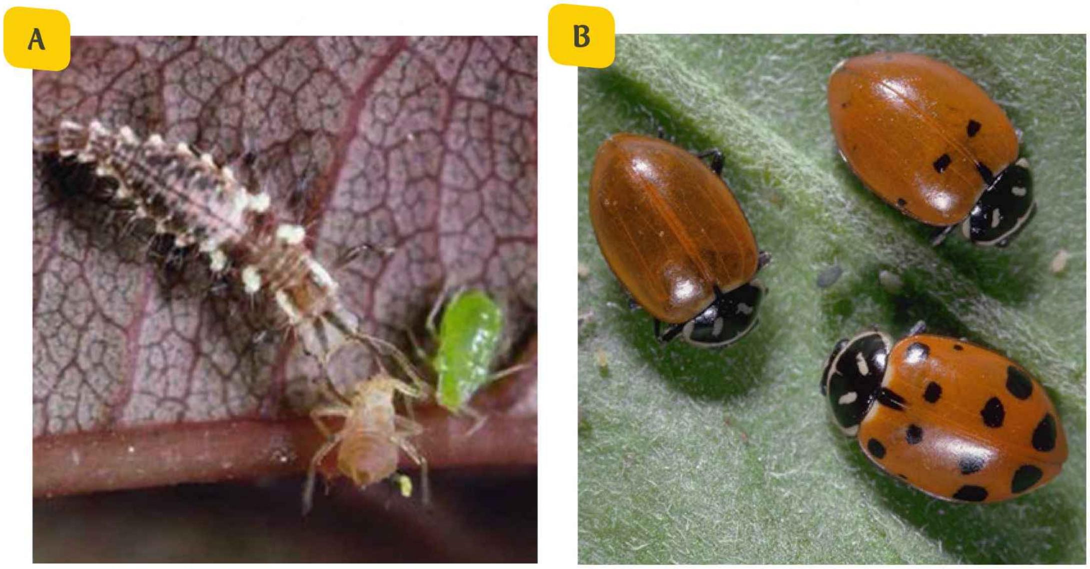
Biological control in the garden is usually used to control insect pests. There are relatively few natural biological control agents for common garden plant pathogens and weeds. Biological control methods typically include conservation and augmentation, with conservation strategies being the most important in home gardens.

Figure 9.2

This parasitic wasp, *Trioxys pallidus*, is laying an egg in a walnut aphid (A). When the parasitoid emerges from its host, it will leave a dried-out shell of the aphid's body (mummy) (B). Note the exit hole. *Photos:* J. K. Clark

Figure 9.3

Predators. Lacewing larvae (A) have strong mandibles (jaws) that they use to grasp their prey. They suck the fluids from soft-bodied insects. Lady beetles (B) feed primarily on aphids. Both predators are found in California and may provide control of garden pests. However, releases of these predators in gardens are generally not effective. *Photos:* J. K. Clark



Many beneficial organisms often occur naturally in home gardens, including non-pathogenic fungi and bacteria; pathogens of insects; parasitic wasps, midges, and flies; and predators such as lacewing larvae, lady beetles, spiders, and predatory mites. Beneficial organisms can be conserved by the judicious use of pesticides and the maintenance of alternative host organisms, including plants, so parasitoids and predators can continue to develop.

The most important thing you can do to encourage the activities of biological control agents is to avoid the use of pesticides whenever possible. Insecticides and some fungicides can reduce the numbers of beneficials, upsetting the ecological balance between pests and their natural enemies. If chemical control is necessary, use the least-disruptive materials, such as soaps, oils, microbials, and botanicals. Listed below are other conservation tactics to help maintain beneficial species in your garden:

- Keep food sources for beneficial species in the garden to enhance the activities of natural enemies. Pollen, nectar, and water are especially important for non-predatory adult stages. Include varieties of flowering plants in the garden that bloom throughout the year. Maintain some organic matter in garden soil so that beneficial fungi and bacteria can sustain or increase their populations.
- Tolerate small numbers of pests. Even though it is best to control pests early, it is also desirable to tolerate some pests to provide food for the beneficials. This can be done by sacrificing some plants in the garden. Moreover, making spot treatment applications of pesticides rather than complete coverage leaves reservoirs of pests on which beneficials can survive. Then, if the pest numbers rise, the beneficials will still be present. If there is no food for the beneficials, they will leave or starve.
- Ants interfere with the ability of predators and parasitoids to control aphids or scales. Exclude ants from colonies of aphids and scales by applying sticky material such as Tanglefoot to the bases of infested plants (fig. 9.4).

Augmentation is the release of natural enemies to increase their population in an area. It can involve increasing existing populations of natural enemies by collecting, rearing, and releasing them back into the environment. It can also involve introducing natural enemies that are not native to the area, which then establish and perpetuate themselves. Typically, when gardeners use augmentation as a biological control technique they purchase beneficials from garden centers or commercial insectaries and release them into the garden. However, more research is needed to determine the effectiveness of augmentation in home gardens. Some of

the commercially available biological control agents that home gardeners may be interested in trying include the following.

Predatory mites. Mass releases of several predaceous mite species have been used successfully against mite pests. Their effectiveness depends on the pest species, the species of biological control agent released, and field conditions.

Parasitic nematodes *(Steinernema feltiae, S. carpocapsae,* and *Heterorhabdtis bacteriophora)*. These tiny parasitic worms have been used to attack soil-dwelling and burrowing insects, including root weevils, lawn grubs, carpenterworms, fungus gnats, and artichoke plume moths.

Mealybug destroyer *(Cryptolaemus montrouzieri)*. This species of lady beetle feeds on mealybugs, small aphids, and scales. It has been used for controlling citrus mealybug and other mealybug species.

***Trichogramma* wasps**. These tiny parasitic wasps attack the eggs of many caterpillar species, including tomato fruitworms, loopers, and hornworms. Results have been mixed because of variable quality in the agents available and lack of reliable release procedures.

Green lacewings (*Chrysoperla* spp.). Green lacewing larvae are general predators that feed on many small insects, including aphids, thrips, pear psylla, insect eggs, and mites. They are often called aphid lions because of their habit of feeding on aphids. Green lacewing eggs are laid on tall stalks. Although lacewings are valuable predators in the garden, research has not shown that releases are efficacious in most situations (see fig. 9.3).

Lady beetles. Convergent lady beetles *(Hippodamia convergens)* are specialized predators that feed primarily on aphids but occasionally also feed on other small insects. Naturally occurring convergent lady beetles often provide effective control and work best in a small backyard situation. Releases may be effective in certain landscape situations when properly handled but often do not provide reliable control because lady beetles rapidly disperse to other areas (see fig. 9.3).

Figure 9.4

A sticky paste works as a barrier to keep ants from entering an area or from reaching honeydew on plants infested with pests such aphids or scale insects. *Photo:* J. K. Clark

Chemical Control

Chemical control methods rely on the use of pesticides to prevent, destroy, repel, or mitigate pests, including insects, mites, snails and slugs, plant pathogens, weeds, and other unwanted home and garden invaders. Pesticides should be used only after the presence of a pest with potential to cause lasting damage is confirmed and when nonchemical methods fail to provide adequate control (see the section "When to Use a Pesticide," below).

Always read the label instructions and follow them explicitly each time any pesticide product is used. Always apply the rates specified on the label, starting with the lowest rate and application frequency. The "if a little is good, more will be better" attitude is hazardous because gardeners expose themselves to the possibility of inhaling or absorbing toxicants each time they spray. Moreover, some home-use pes-

ticides are sold in concentrated formulations and can be especially hazardous if not used or handled properly. Other adverse effects of misusing or overapplying pesticides may include plant injury, unsafe pesticide residues on edible crops, and pollution of water supplies. Beneficial insects, earthworms, fungi, birds, and pets may be harmed or killed. Moreover, repeated use of pesticides can lead to the development of pesticide resistance in the target pest; overreliance on broad-spectrum pesticides can cause previously minor pests to become serious problems.

Master gardeners may use pesticide products in demonstration gardens, but they must be used in accordance with the label and all state and federal laws. UC Cooperative Extension staff should approve any pesticide applications and provide adequate training for demonstration applications.

When to Use a Pesticide

Pesticides are most effective when they are applied at the correct time. Do not use pesticides to control insect and mite pests unless you are certain they are present and actually causing damage. Perform early detection so that they are easier to control by inspecting plant foliage on a regular basis, paying particular attention to the underside of leaves, where they frequently occur. Observations and monitoring should also be used to determine whether beneficials are adequately controlling the pest. However, certain fungicides must be applied in anticipation of weather conditions that are favorable to plant diseases. For instance, fungicides can be applied to peach trees in the fall or winter to control peach leaf curl, which appears in the spring. An herbicide application before weed seeds germinate may be recommended to manage certain weed problems.

Proper timing of any pesticide requires information about the pest's life cycle and environmental conditions that favor the pest. With most pests, only certain life stages are susceptible to control by pesticides. For instance, if you are using a stomach poison insecticide to control a leaf-feeding moth, the pesticide works only when the insect is in a larval stage, because the other life stages (adult, pupae, eggs) do not feed on leaves.

The location of the pest is also important when using pesticides because pesticides must contact the pests in some way. For example, it is unlikely that a worm inside an apple will be controlled with a pesticide sprayed on the apple's surface. Pests that move elsewhere after migrating into an area to feed, such as grasshoppers, will usually be controlled only if the application is made when they are in the area being treated.

Many types of pesticides lose their effectiveness or cause damage to treated plants during certain weather conditions. Extremes in temperatures may render some pesticides ineffective. Fog, rainfall, or irrigation may wash pesticides off treated surfaces so they cannot function properly. High temperatures, wind, and lack of irrigation may cause treated plants to become stressed, and these plants may be damaged by the pesticides applied to them. This is especially true of the soaps and oils used to control insects and mites.

Proper timing may also contribute to the selectivity of certain pesticides. For example, dormant sprays of oils and insecticides help control overwintering insect and mite pests on deciduous trees without affecting natural enemies, as they would if applied during spring or summer. Many herbicides have specific uses based on timing of applications:

Preplant: use before planting by applying to the soil.

Preemergent: use before weed seeds germinate and plants emerge from the soil.

Postemergent: use after the weeds have germinated and emerged from the soil.

When fruits and vegetables and other edible crops are involved, gardeners must

comply with the preharvest interval if one is indicated on the label. This interval is the minimum number of days that must elapse between application of a pesticide and harvest.

Selecting a Pesticide

If a pesticide must be used, choose one that is effective against the identified pest and poses as little risk as possible to human health, the environment, and beneficials. Although you must check the label to make sure the target pest is listed, do not use labels as your primary source for selecting the pesticide product, because the label may include pests that are only marginally controlled. The UC IPM Pest Management Guidelines, ipm.ucdavis.edu, are a good source of current information and recommendations for the effective management of garden pests; also see the reduced-risk pesticides listed in the "Home Garden Pesticides" section, below.

Products with identical active ingredients are offered for sale by different manufacturers, but formulations, pests, and sites listed on their labels may vary. Therefore, always check the label to be sure it is appropriate for use before purchasing. The specific plant you will be treating must be listed on the label or referred to under a general heading (e.g., trees, shrubs, lawns, ornamentals, vegetables, fruit trees). Also check the label to ensure that the product will not cause injury to plants that will be treated. Do not use pesticides labeled specifically for ornamentals on plants that will be eaten. Never use pesticides labeled specifically for outdoor use in homes, greenhouses, or other indoor locations.

Classification of pesticides

Pesticides are categorized in several ways.

Categorization by the target pests. Three common groups of pesticides are classified by the target pests they are intended to control: insecticides (insects); herbicides (weeds); and fungicides (fungal diseases). Other examples include miticides (mites), molluscicides (slugs and snails), nematicides (nematodes), and rodenticides (rodents).

Categorization by the effect of the pesticide on the pest. For example, attractants lure pests; repellents repel pests; desiccants and defoliants remove or kill leaves and stems; and plant growth regulators alter normal growth processes.

Categorization according to how the active ingredient reaches the target pest. Examples include

- contact pesticides: kill when the pesticide touches the target organism
- stomach pesticides: must be ingested by the pest
- systemic insecticides and fungicides: carried in the tissues of treated plants to protect them from pests that feed on plant parts
- translocated, or systemic, herbicides: move from the point of initial application to other parts of the plants, where they interfere with plant biochemical processes, resulting in plant death
- fumigants: pesticides that kill pests in the pesticide's gaseous phase

How the chemical reaches the target pest can determine the type of pesticide selected. For example, chewing insects (e.g., caterpillars) are targets of stomach poisons, whereas piercing-sucking insects that feed on plant sap (e.g., aphids, mites, whiteflies, psyllids) may be more effectively killed by a systemic pesticide. A systemic fungicide may be a better choice as a preventive, while a contact fungicide would be used when trying to manage a small disease outbreak quickly. A systemic insecticide may be selected over a contact pesticide to limit impact to nontargets or to effectively kill sap-sucking pests that are hidden in buds or curling foliage.

Categorization by selectivity. Pesticides can be selective or nonselective. Selective pesticides kill only certain organisms in a related group or species; nonselective, or broad-spectrum, pesticides kill a wide range of plants or animals. Although selective pesticides are generally preferred in IPM programs because they reduce the

impact on target organisms, both types of pesticides have a place in home gardens. For instance, to kill broadleaf weeds in a lawn, pick a selective herbicide that kills only broadleaf plants; however, to kill the whole lawn (weeds and grass), choose a nonselective herbicide.

Categorization by persistence. Pesticide persistence is a measure of how long a chemical resists degradation. Typically, degradation by microbial and chemical reactions in the soil eventually detoxifies a pesticide, which is a desirable process from the perspective of environmental safety. However, fast degradation may render a pesticide ineffective for pest control if it must be applied precisely when the vulnerable stage of the pest is present; a balance between persistence and efficacy is desirable. The use of highly persistent pesticides poses the greatest risk of groundwater and surface water contamination.

Categorization by the source of the pesticide material. Examples include botanicals or plant extracts such as neem oil; inorganic pesticides such as sulfur and copper; synthetic pesticides such as organophosphate and chlorinated hydrocarbon insecticides; and biological extracts or fermentation products. Organic pesticides are derived from natural sources, not synthetically manufactured. These include botanicals, plant extracts, and biological extracts or fermentation products. Pesticides that are used by organic farmers also include certain minerals or inorganic natural elements, such as copper or sulfur.

Categorization by risk. Pesticides conventionally used in home gardens such as organophosphates are broad spectrum and persistent. Although they control a broad range of pests, these pesticides typically pose hazards to the environment and kill natural enemies. Newer types of garden pesticides are reduced-risk pesticides (biorationals). These pesticides are IPM compatible: they have low toxicity, are typically targeted to specific pests, and have very low impact on the environment. Note that organic pesticides are not necessarily reduced risk: for example, rotenone is extremely toxic to fish and other aquatic life, and pyrethrins and sabadilla are very toxic to honey bees.

Pesticide formulations

A pesticide you purchase will be a mixture of the active ingredients and other materials (inert ingredients) combined into a pesticide formulation. The active ingredient is the material in the pesticide that actually destroys the pest or performs the pesticide's intended function. Inert ingredients, substances having no pesticidal action, are usually added to improve storage, handling, application, effectiveness, or safety. The name and percentage of active ingredients and the percentage of inert ingredients are given on the label (see the section "Pesticide Label," below). The type of formulation determines how the product will be applied and how it should be mixed before application.

Ready to use (RU). Ready-to-use pesticides are the most common formulation for the home gardener. These are usually packaged in squirt bottles (trigger-pump sprayers), already diluted and ready to use. For many home gardeners, this type of formulation is the safest and most effective type of product. There is no need to mix and measure, less chance of improper concentration, and no leftover solutions to dispose of.

Emulsifiable concentrates (EC or E). The active ingredient in an EC formulation is mixed with an oil base, forming an emulsion that is diluted with water for application. Dilution rates are often in teaspoons, tablespoons, or ounces per gallon of water. They are widely available in the home garden trade and are easy to mix and use. They can injure sensitive plants or plants stressed by heat, wind, or lack of moisture. They should be protected from freezing temperatures, which can break down the emulsifier. They are not soluble and require some agitation to keep them in suspension.

Solutions (S). Some pesticide active ingredients dissolve readily in a liquid car-

rier, such as water or a petroleum-based solvent. Once prepared by dilution in water, they form a solution that does not settle out or separate, requiring no further mixing or agitation.

Flowables (F or L). Flowable, or liquid, pesticides can be mixed with water to form a suspension in a spray tank. They require constant agitation or they will settle out.

Aerosols (A). Aerosols are low-concentrate solutions, usually applied as a fine spray or mist directly from the container. They are generally sold in aerosol cans and are convenient but relatively expensive.

Wettable powders (WP or W). Wettable powders are made by combining the active ingredient with a fine powder. They look like dusts, but they are formulated to be mixed and diluted with water. The spray tank must be shaken frequently to maintain the suspension of particles in the water. Wettable powders are less likely to cause phytotoxicity damage to plants than are emulsifiable concentrates.

Soluble powders (SP). Soluble powder formulations dissolve when mixed with water. Constant agitation is not needed to keep them in solution.

Baits (B). A bait formulation is made by adding the active ingredient to an edible or attractive substance. Baits are often used to control slugs, snails, ants, and rodents. They are applied directly from the package. Care must be taken in their use, as pets and other nontarget organisms may be attracted to baits.

Granules (G). Granular formulations are made by adding the active ingredient to coarse particles (granules) of inert material such as fired clay. They are applied directly from the package without dilution.

Dusts (D). Some dust formulations are made by adding the active ingredients to a fine, inert clay or talc. Others, such as some sulfur dusts, are pure active ingredient. Dusts are applied directly from the package without dilution. Most can be shaken out or "puffed" from the container in which they were purchased; some require the use of a duster to apply them. Dusts should not be confused with wettable powder formulations, which are mixed with water and applied as a spray.

Adjuvants

Adjuvants are chemicals added to pesticide mixtures to enhance the active ingredients, improve coverage, or resist weathering after application. The addition of certain adjuvants is a common practice in some commercial pesticide uses. Numerous adjuvants are on the market, but most are too expensive and are unnecessary for home gardeners. Pesticides sold for home garden use may already contain certain adjuvants to make them easy to mix and apply. Home gardeners with special needs that require using adjuvants should consult *The Safe and Effective Use of Pesticides* (O'Connor-Marer 2000), which contains detailed information about different types of adjuvants.

Home Garden Pesticides

Many types of pesticides are packaged specifically for home and home garden use. These products are packaged in small containers and often in ready-to-use formulations. When these materials must be diluted before use, the dilution rates are often given in spoonfuls per gallon of water or ounces per 1,000 square feet of treated area.

Products packaged for commercial use are not recommended for home gardeners and may be illegal to use for this purpose. Commercial pesticides are generally more concentrated than formulations for home use and require additional protective clothing and equipment for application. Commercial formulations typically contain more product than the consumer could expect to use or safely store, and they are much more difficult to mix precisely, since rates are usually based on large areas. Moreover, commercial products with restricted-use labels can be

legally sold to and applied only by certified applicators or persons under their direct supervision.

Certain pesticides are especially compatible with IPM programs because they have low impact on natural enemies of pests and low toxicity to people and animals. These reduced-risk products usually break down rapidly in the environment. They are packaged in small volumes and are readily available in garden supply stores for home use. Consider using the reduced-risk products listed below when a pesticide is warranted. More information about specific pesticides used in home gardens can be found at the UC IPM Pesticide Information website, ipm.ucdavis.edu/GENERAL/pesticides.html.

Bacillus thuringiensis (Bt). Microbial insecticides such as Bt are commercially available formulations of microorganisms or their toxins that cause disease in specific groups of insects but have no effect on other organisms. The bacteria in the insecticide are harmless to warm-blooded animals and beneficial insects. The use of microbial insecticides is, in a sense, biological control. Microbial insecticides are almost ideal insecticides and have little impact on the environment or human health. At present, Bt is the most commonly used microbial insecticide for garden pests. Bt controls many species of lepidopteran larvae (butterflies and moths), coleopteran species (beetles), flies, fungus gnats, and mosquito larvae, depending on the variety of Bt used. For example, Bt *israelensis* specifically kills flies and is effective against fungus gnats and mosquitoes. For caterpillars, spray Bt as soon as you find eggs hatching, as it works best on newly emerged insects. Make sure all leaf surfaces are well coated with insecticide. Caterpillars infected by the bacteria stop eating, and their internal tissues disintegrate and liquefy. Multiple applications may be necessary.

Pyrethrins. Pyrethrins (pyrethrin, pyrethrum) are botanical insecticides (plant derivatives) that are derived from the flowers of a *Chrysanthemum* spp. plant imported mainly from Kenya and Ecuador. The material causes rapid paralysis and controls a broad spectrum of insects, including mosquitoes, flies, aphids, beetles, moth larvae, thrips, and mealybugs. Pyrethrins are registered for use on most vegetables and fruits at any time during the growing season. Because pyrethrins break down quickly, they must be applied precisely when and where susceptible insects are located; pests that migrate in after application will probably not be controlled. Multiple applications may be necessary. Insects may recover from application of pyrethrins alone; to be most effective, applications must be combined with the synergist piperonyl butoxide. Formulations that include insecticidal soap or other insecticides may increase effectiveness. Many pesticides for use in home gardens contain pyrethrins. Some example products are found on the UC IPM Pesticide Information website, ipm.ucdavis.edu/GENERAL/pesticides.html.

Spray oils. Horticultural spray oils have several advantages over conventional pesticides. Oils have a wide range of activity against many soft-bodied arthropod pests, yet are less harmful to beneficials than most other pesticides because they leave no toxic residues after application. Residual insecticides can kill natural enemies for long periods after a spray. Although oils may kill nonmobile and exposed pests such as scales or aphids, beneficials that are not located on treated surfaces at the time of the spray survive. In addition, oils are relatively nontoxic to people and are environmentally friendly. No cases of insecticide resistance to oil have been observed in target pests. Highly refined horticultural oils can be used on trees, shrubs, and other plants during the growing season for control of mites and many soft-bodied insects such as aphids, immature scales, whiteflies, mealybugs, and psyllids. The main use of oil sprays during the dormant season is to control scale insects. In addition to oils derived from

petroleum, many plant-based oil insecticides are now available, including neem oil, jojoba oil, and canola oil. These oils work as fungicides as well as insecticides. Because injury can occur, do not apply oils when temperatures are over 90°F or when plants are drought stressed. Check labels for plants that are sensitive to oils.

Insecticidal soap. Gardeners have been using soap to control insects since the early 1800s. Researchers have not yet determined exactly how soaps work. Some soaps dissolve the outer waxy coating of insect cuticle, destroying its watertight nature and causing desiccation. This is why soaps are most effective against soft-bodied insects. Insecticidal soaps control mites, aphids, whiteflies, and other plant-sucking arthropods. Soaps, like oils, kill only on contact, so they are less harmful to beneficials than are residual pesticides, and they are compatible with biological control. However, repeated applications may be necessary. Commercial products containing soaps for home use are registered on a wide range of fruits and vegetables. They are similar in toxicity to a solution of soapy dishwater. Check product labels for plant species that are sensitive to soap.

Pesticide Laws and Regulations

The registration and use of pesticides are regulated by the U.S. Environmental Protection Agency (EPA) and the California Department of Pesticide Regulation (DPR). Locally, laws are enforced by the county agricultural commissioner.

Pesticide Label

The safe and legal use of pesticides requires adherence to the printed information provided by the manufacturer or formulator of a pesticide. Pesticide labels include the label on the product container plus any brochures or flyers with additional use instructions or limitations. The label printed on or attached to a container of pesticide tells how to use the product correctly and what special safety measures must be taken. Read this information carefully before using a pesticide. Pesticide labels are required to follow a specific format and usually must include each of the following sections. Use the sample pesticide label illustrated in figure 9.5 to locate these sections. Sections on the sample label are numbered 1 through 8 to correspond to the numbers listed below.

1. Brand name. A brand name is the name the manufacturer has given to the product. It is the name used for all advertising and promotion and is usually the largest and most conspicuous wording on the label. Do not confuse the brand name with the chemical name and the common name of the pesticide, which are listed in the active ingredients section of the label (a common name for the pesticide is not given on all labels). The chemical name describes the chemical structure of a pesticide and is derived by chemists based on international rules for naming chemicals. Most pesticide chemicals also have an official common name assigned to the active ingredient; this is a generic name, and it may be found on the label of many brands if each contains the same active ingredient. For example, N-(phosphonomethyl) glycine (chemical name) is the herbicide glyphosate (common name), which is sold under many brand names, including Advanced Garden Power Force, Weed and Grass Killer, Roundup, and others.

2. Formulation. The formulation is the way the active ingredient is mixed with inert ingredients to make it ready for you to use. Many pesticides for use in home gardens are ready-to-use formulations. Other formulations require measuring and diluting with water.

3. Ingredients. Active ingredients are the chemical or common name of the pesticide; these are the chemicals that control the pests listed on the label. All of the active ingredients in a pesticide formulation must be listed on the label and are given as percentages by weight. Inert ingredients are other ingredients in the product that do not control the pest but carry the pesticide or dissolve the active ingredients. These nonpesticide ingredi-

Figure 9.5

Know how to find the different parts of a pesticide label. Be sure to read the entire label, including brochures attached to the container. If you are not sure you understand the label, get help.

1 Trade brand name. This is the name the manufacturer has given the product. It is used for marketing purposes and is not a reliable guide to the actual chemical makeup of the product.

2 Formulation. The formulation describes the way the active ingredient is mixed with other ingredients to make the product ready to mix or use. Many pesticides used in home gardens are ready-to-use formulations.

3 Ingredients. The active ingredient is the pesticide chemical with the toxic effect. The inert or other ingredients do not need to be named. Both are listed as percentages.

4 Signal word. At registration, every pesticide is assigned a toxicity category that indicates its level of acute toxicity and prescribes the signal word that must be used on the label, either DANGER, WARNING, or CAUTION. Products with the DANGER signal word are the most toxic. Products with the signal word CAUTION are lower in toxicity. Signal words do not indicate potential long-term effects such as cancer. Moreover, signal words do not reflect potential hazards to nontarget organisms and the environment. All products must bear the statement Keep Out of Reach of Children.

5 Manufacturer.

6 U.S. EPA registration and establishment numbers. Every pesticide has a registration number assigned to it. The establishment number is the code that indentifies the site of manufacture or repackaging.

7 Precautionary statements. These describe the human environmental hazards associated with a pesticide, how to avoid exposure, personal protective equipment required, and how to store and dispose of it. It includes first-aid instructions and may include instructions for physicians.

8 Directions for use. This section lists the plants or sites and the target pests on which the pesticide may legally be used. It tells how to mix and apply the pesticide, and how much to use. Always follow these directions carefully.

ents may be toxic, flammable, or pose other safety or environmental problems. Some, however, are harmless. Only inert ingredients approved by EPA are allowed to be used in pesticide products, although the exact composition may be protected as a trade secret. The inert ingredients may not be listed by chemical name if the label shows what percentage of the total material in the formulation is inert ingredients.

4. Signal words. All products must bear the statement Keep Out of Reach of Children on the front of the label. Near this statement you will usually find one of the signal words CAUTION, WARNING, or DANGER (in all capital letters, to make it easy for users to find). The signal word that manufacturers must use on their labels is a guide to the user as to the immediate toxicity (or danger) of the formulated pesticide product. The only pesticide products that are not required to display a signal word are those that fall into the lowest toxicity category by all routes of exposure, including oral, dermal, respiratory, and ocular (fig. 9.6), as well as other effects, such as eye and skin irritation.

Signal words indicate three levels of acute (short-term) toxicity. CAUTION means that the pesticide product has low toxicity or very low toxicity if eaten, absorbed through the skin, or inhaled, or that it causes slight eye or skin irritation. WARNING indicates that the pesticide product is moderately toxic if eaten (e.g., 1 tsp to 1 oz could be lethal if ingested), absorbed through the skin, or inhaled, or that it causes moderate eye or skin irritation. DANGER means that the pesticide product is highly toxic by at least one route of exposure. It may be corrosive, causing irreversible damage to the skin or eyes. Alternatively, it may be highly toxic if eaten (e.g., just a taste could be lethal if ingested), absorbed through the skin, or inhaled. If this is the case, then the word POISON must also be included in red letters on the front panel of the product label (National Pesticide Information Center 2008).

Although most home and garden products are sold with the signal word CAUTION, verify the actual term used before purchasing. Products with a WARNING or DANGER signal word are generally not recommended in home gardens. If you are considering using a product with a DANGER or WARNING signal word, you must carefully read the safety precautions on the label, especially those regarding protective clothing and where the product may be safely used. Regardless of the signal word on the pesticide product, remember that every product has the potential to poison if the dose is high enough.

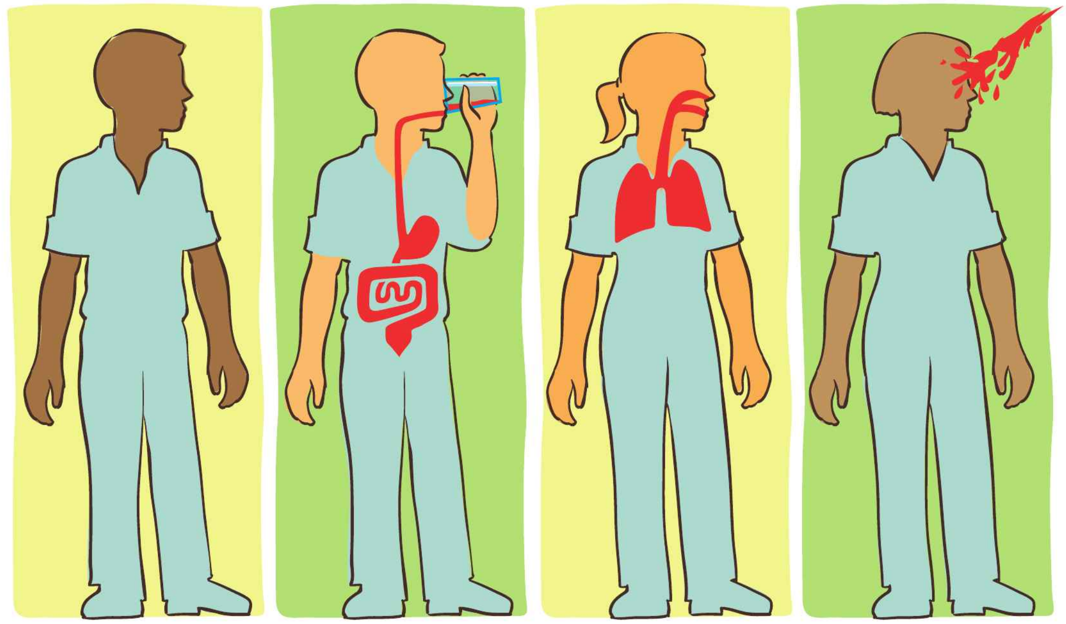
5. Manufacturer. Each pesticide label must include the name and address of the company manufacturing and distributing the pesticide. Use this information if you need to contact the manufacturer for any reason.

6. Registration and establishment numbers. All pesticide products sold in the United States must be registered with the EPA. The EPA assigns a registration number to each pesticide that shows the product has been reviewed and approved. If there is a pesticide injury or illness, the EPA registration number is required to identify the actual product that was the cause and to get the best medical treatment. The California EPA (Cal/EPA) also registers (approves) the product before it is legal to use in California. Some products have only a California registration number (e.g., adjuvants require California registration). Be very careful of purchasing pesticides over the Internet or through magazines, since all pesticides you use must be registered by Cal/EPA and EPA. In addition to the EPA registration number, each pesticide has an EPA establishment number, which is a code that identifies the site of manufacture or repackaging.

7. Precautionary statements. This part of the label explains how to avoid problems and provides important safety information. It includes first-aid instructions and often has information for

Figure 9.6

The most common ways for pesticide exposure to occur are through the skin (dermal), through the mouth (oral), through the lungs (respiratory), and through the eyes (ocular).



Skin contact is the most common type of pesticide exposure. If some pesticides contact the skin, they may cause a skin rash or mild skin irritation. Other pesticides may cause more severe skin injury, such as burns. Pesticide absorbed through the skin can cause internal poisoning: the blood carries the pesticide to other organs in the body.

It is rare for someone to accidentally drink a pesticide. More often, pesticides are taken in when spray materials or pesticide dusts splash or blow into your mouth during mixing or application. Sometimes pesticides are taken in when someone eats or drinks contaminated foods or drinks. Smoking while handling pesticides increases your risk of taking in pesticides.

The lungs quickly absorb certain pesticides. The blood transports these pesticides to other parts of the body. Some pesticides cause serious lung injury. Use the correct respiratory protective measures to avoid breathing dusts and vapors during mixing or application.

The eyes provide another way for pesticides to get into your body. The active or inert ingredients of some pesticide formulations are caustic to the eyes.

physicians. It also includes information on storage and disposal and what to do with unused product and empty containers. This is important because some pesticides may become ineffective if improperly stored or stored for a long time, and improper storage may even cause explosions or fires. Always read and follow the instructions and protective measures given in the precautionary statement.

Three types of hazards may be addressed in precautionary statements: hazards to humans and domestic animals, environmental hazards, and physical and chemical hazards. Human and domestic animals hazards include adverse effects that may occur if people or pets become exposed. The precautionary statements include the type of protective equipment to wear while handling pesticides and when mixing and applying the product. Instructions will also be provided on ways to prevent exposure to people or pets. Environmental hazards include potential toxicity of the specific pesticide product to nontarget organisms, such as wildlife, fish, birds, endangered plants, honey bees, or other animals, and the risks of using the pesticide near wetlands or other water resources. Physical or chemical hazards include the flammability of the product or possible problems that can occur when the product is mixed with other chemicals (see Cohen et al. 2009).

8. Directions for use. This part of the label specifies the target pests and crops, plants, animals, or other sites where you can use the pesticide. It also tells you how and when to apply the pesticide, how much to use, how to mix it, and where to

use it. Manufacturers may include a booklet on the container that outlines how to use the product. Read this before use. For questions, some labels provide a toll-free telephone number for the manufacturer.

Always follow the instructions in the directions for use. It is a violation of law to use pesticides in a manner inconsistent with the label unless federal or state laws specify acceptable deviations from label instructions. Under the amended Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), it is illegal to use a pesticide on a site not listed on the label. Therefore, if the pesticide label lists specific plants that the pesticide can be used on and your plant is not on the label, it is illegal to use that product on your plant. Sometimes, however, the label refers to broad categories of plants that the pesticide can be used on, such as ornamentals. It is also illegal to exceed the rate of application given on the label. Using higher-than-label rates can result in hazardous residues on edible crops or cause injury to the plants being treated.

Liability

Home gardeners are liable for misuse of pesticides on their property. Misuse can result in injury to people, animals, desirable plants, and the environment. The federal Clean Water Act of 1987 requires elimination of discharge of pollutants, including pesticides, into surface water to the maximum extent possible. See "Protecting Nontarget Organisms and the Environment," below, for ways to prevent pesticides from polluting bodies of water. In addition to federal regulations, California has several state laws restricting the use of pesticides within the state. Proposition 65 (The Safe Drinking Water and Toxic Enforcement Act of 1986) mandated the creation of a panel of experts to review all pesticides registered for use in California to determine the carcinogenic and reproductive hazards of each chemical, and it also requires that warnings be given to people who might be exposed to the regulated chemicals.

Pesticide Safety

Preventing Pesticide Poisoning

Most home and garden products are relatively safe if label directions are carefully followed. However, misuse of pesticides can result in severe illness or even death. The likelihood that injury will occur depends on the degree of toxicity of the active ingredient and the amount of exposure to the product during or after use. To avoid injury, applicators must understand several key points about pesticides and follow the pesticide label directions carefully.

Acute toxicity is the immediate toxicity of a single exposure of a product to humans. Overexposure to some pesticides can cause immediate, or acute, illnesses or injuries, such as headaches, skin rashes, nausea, or muscle weakness. Signal words indicate three levels of acute toxicity: CAUTION, DANGER, and WARNING. However, signal words do not give an indication of potential for causing certain long-term or chronic diseases such as cancer, reproductive disorders, birth defects, neurological disorders, or allergies. Chronic health problems may be difficult to associate with pesticide exposure because symptoms may not appear for months or years after the exposure incidents occurred. Information on chronic disease potential, risks to the environment, other harmful effects, and additional safeguards that should be taken can be found in precautionary statements on the label. For more information on hazards of specific pesticides, review the Material Safety Data Sheets (MSDS) available from the pesticide manufacturer, or contact the National Pesticide Information Center (npic.orst.edu).

To avoid illnesses or injuries of any type when using or handling pesticides, you must take precautions that protect yourself from exposure. Injuries can occur when pesticides contact the skin or eyes. Sometimes these injuries are limited to the areas of the body that received the exposure. However, pesticides can also be absorbed

into the body by inhalation (breathing), absorption (through the skin) or ingestion (swallowing) (see fig. 9.6). Pesticides that enter the body may cause serious illness or may damage internal organs. Wear protective clothing to help keep pesticides off your skin and out of your eyes and to prevent these toxic chemicals from entering your body, even when applying the safest pesticides. See "Protective Equipment and Clothing," below, for a description of the types of protective clothing required.

Keep other people and animals away from areas where you are applying pesticides. Do not let spray droplets or dust get onto people, animals, food, clothing, or anything other than the target plants or surfaces you are treating. Keep pesticides in their original containers with the labels attached. Never put any pesticide in food or beverage containers. Children, the most frequent victims of pesticide poisoning in homes, have been seriously injured because they drank from containers in which pesticides had been stored (fig. 9.7). Store pesticides where children and other people cannot reach them in a locked cabinet.

Symptoms of Pesticide Poisoning

General symptoms of pesticide poisoning must be recognized so that medical care can be obtained promptly. Unfortunately, all pesticide poisoning symptoms are not the same. The most common poisonings resemble the flu, with symptoms such as nausea, headache, and malaise. A person may feel tired and ill but not even realize that something as serious as pesticide poisoning has occurred.

Common symptoms of poisoning associated with some pesticides include the following:

- **Mild exposure**: Fatigue, headache, dizziness, blurred vision, excessive sweating and salivation, nausea and vomiting, stomach cramps, or diarrhea.
- **Moderate exposure**: Inability to walk, weakness, chest discomfort, muscle twitches, constriction of pupils of the eyes. Mild exposure symptoms become more severe.
- **Severe exposure**: Unconsciousness, severe constriction of pupils of the eyes, muscle twitches, convulsions, secretions from mouth and nose, breathing difficulty, and death if not treated. Illness may occur a few hours after exposure.

First-Aid Procedures for Pesticide Overexposure

Read and become familiar with the Statement of Practical Treatment on each label for the pesticides you plan to use. Know-

Figure 9.7

Children are the major group of nonagricultural pesticide poisoning victims. Improper storage of pesticides in the home is the prime reason for the problem. *Photo:* J. K. Clark

Figure 9.8

If pesticide gets into the eyes, they must be flushed immediately for 15 minutes with a gentle stream of clean water. Hold eyelids open while flushing. If irritation still persists, obtain medical treatment. *Photo:* J. K. Clark

ing how to perform the first-aid procedures described in these directions can save lives and prevent serious injuries. Whenever you suspect pesticide poisoning, call 9-1-1 and seek emergency medical care immediately!

The most common way to be exposed to a pesticide is through the skin. If a pesticide gets on your skin, remove the pesticide as quickly as possible by taking off contaminated clothes and washing with soap and plenty of running water. Prompt washing reduces the damage to the skin and lessens the amount of pesticide absorbed into the body.

If someone inhales pesticide vapors, get them into fresh air right away. Loosen all tight-fitting clothing. If needed, give artificial respiration immediately. Do not stop until the person is breathing regularly or medical help arrives.

If a pesticide is splashed into an eye, start rinsing the eye immediately with a steady, gentle stream of clean, cool water. Make sure the eye is open during rinsing (fig. 9.8). Do not add any eye drops or other medications to the eye. Continue rinsing for at least 15 minutes; seek medical care immediately.

If someone has swallowed a pesticide, get medical care immediately. Follow the first-aid instructions on the pesticide label. Some labels suggest making the person vomit, but others warn against this.

If a person shows signs of pesticide poisoning, immediately call an ambulance or transport the victim to the nearest medical facility. Provide the attending physician with as much information about the pesticide as possible, including the common or generic name of the active ingredient, how the person was exposed (inhaled, splashed on skin or into eyes, or ingested), and, if known, how much exposure occurred. Try to provide the name of the manufacturer and the U.S. EPA registration number. If the person has vomited and the identity of the pesticide is not known, collect some of the vomit in a clear jar for analysis.

If for some reason you cannot take the victim to a medical facility immediately, contact a regional poison control center. These are located throughout the state and can be reached by telephone at any time. These centers provide quick, life-saving information on treatment for poisoning, but they should be called only in an actual emergency. Most telephone directories list

the nearest center in the white pages, usually with other emergency numbers. Locate the number and post it in your pesticide storage area or near a telephone for quick access in an emergency. If you cannot locate the number in an emergency, dial 9-1-1.

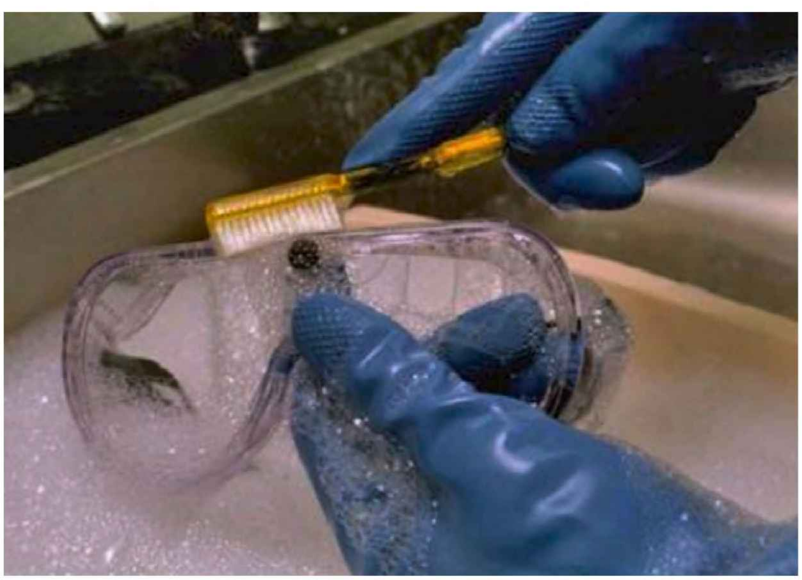
Protective Equipment and Clothing

Pesticide labels provide information on the type of protective equipment and clothing to wear during mixing and application. Home gardeners should never apply pesticides while wearing clothes such as shorts or sandals. Minimal attire for applying pesticides is a long-sleeved shirt, long-legged pants, closed shoes, unlined rubber gloves, and safety glasses. Additional protection is provided by a wide-brimmed plastic hard hat that covers the back of the neck. Rubber gloves are particularly important when mixing or pouring concentrated pesticides; avoid cotton gloves that may absorb pesticides and prolong contact with the skin.

Keep this protective equipment separate from all other clothing and use it only for pesticide applications. After each use, wash the clothing, gloves, safety glasses, hard hat, and apron in soap and water (fig. 9.9) separately from other laundry. If any of these items becomes seriously contaminated with a concentrated pesticide, throw them away.

Figure 9.9

After each use safety glasses, gloves, and protective clothing should be washed in soap and water. *Photo:* J. K. Clark



Mixing Pesticides

Properly measuring concentrated formulations of pesticides is essential for their effective and safe use. Always consult the label for the application rate and mixing instructions. It is critical that pesticides be diluted and applied exactly as specified on the label. Most serious injuries occur when mixing pesticides because mixing involves handling undiluted formulations. The mixing process can be avoided by purchasing ready-to-use formulations. The extra cost will be offset by the convenience and safety of not having to mix concentrated materials.

If mixing is necessary, check the pesticide label for appropriate protective clothing and equipment. Avoid using metal measuring utensils. Take care that measuring equipment is not mistaken for kitchen utensils: have a set of measuring cups and spoons especially for your pesticide dilutions, and label them as such with an indelible marker. If measuring outdoors, stand upwind to reduce chances of exposure. When measuring indoors, work in a well-lit and well-ventilated area. Reduce exposure hazards to your face and eyes by measuring and pouring below eye level and by wearing eye protection. Open paper containers with a sharp knife or scissors rather than tearing the bags open.

Pesticide Application

When applying pesticides, wear the protective clothing and equipment recommended on the label. Before adding a pesticide, check application equipment for leaking hoses or connections and plugged, worn, or dripping nozzles. Always have on hand a bag of absorbent material, such as kitty litter or sand, in case you have a spill.

After application, thoroughly clean the inside of the spray equipment and rinse with water immediately. Remember to flush the hoses and nozzles. Do not dump

the rinse water in a place where it will collect or puddle and become a pollutant. The rinsate should be sprayed onto a site listed on the label. Never pour pesticide-contaminated rinse water down the drain!

When washing protective equipment, leave gloves on to avoid hand contamination. After everything else has been cleaned, wash the outsides of your gloves with soap and water before taking them off; then wash your hands thoroughly. Shower as soon as possible, using plenty of soap and water. Never smoke, eat, or use the toilet after a pesticide application without washing first.

Some pesticides can damage and even kill the plants they are intended to protect. Before using pesticides, always check the label for plants on which the pesticide may be used safely. All cultivars and varieties may not be listed, and unlisted plants could be injured by the product. (Also, if the label lists specific plants rather than general categories of plants, applying the pesticide to plants not included on the list is illegal.) Some types of pesticide formulations are more prone to injure plants. For example, emulsifiable concentrates are more likely to cause leaf burn than wettable powders. If you are unsure of the effect of a pesticide, apply it to a small area first before treating the entire plant.

To avoid plant injury, apply pesticides only at recommended dosages; increased amounts can be hazardous, cause plant damage, and leave harmful residues without improving pest control. Do not apply pesticides to wilted plants or during the hottest parts of the day. Dusts should be applied only when the plants are dry. Avoid using old pesticides because they may become chemically altered from long periods of storage, which can lead to problems such as plant injuries.

Use a different sprayer for weed control than you use for insect and disease control. No matter how well a tank is rinsed after herbicide use, small amounts of residue can still remain in the tank, on gaskets, and in hoses. If the same tank is then used to apply an insecticide or fungicide to plants, these residues may injure them. The wisest policy is to maintain two clearly labeled sprayers, one for herbicides and another for insecticides and fungicides.

Insecticides and fungicides can usually be safely applied using the same sprayer. However, when combining two or more pesticides in the same sprayer, always check the label of each product to determine whether they can be mixed together safely. Incompatibility can reduce pesticide efficacy and injure plants. If there is no information on the label about mixing products together, it is safer to apply them separately.

Storage and Disposal

You can reduce the need to store pesticide products by purchasing only the amount of pesticides you can use in the immediate future. If you cannot use pesticides in a timely manner, try to share them with someone; but if you do, always keep these materials in their original containers. Pesticides that must be stored should be secured in a locked cabinet and kept in their original containers. Stored pesticides should be protected from temperature extremes, as some pesticides are damaged by freezing, while others are altered by heat.

Mix up only the amount of pesticide needed for the present application. If you end up with leftover pesticide solution, apply it to a plant or site listed on the label. Do not pour leftover pesticide solution down the drain, onto the soil, or into gutters, storm drains, sewers, or open waterways. Likewise, do not dump leftover pesticides in the trash or store mixed solutions.

Follow any label instructions concerning disposal of containers and unused product. Never use empty pesticide containers for other purposes, and never allow children to play with empty containers. On the day of your street-side trash collection, you may dispose of most empty home garden–use pesticide containers in the trash. The only legal way to dispose of

containers that are not empty is at your local household hazardous waste disposal facility. Many communities provide household hazardous waste collection services at periodic intervals, which can be used to dispose of unwanted or old pesticides. For information on pesticide hazardous waste collection and disposal, contact your local county agricultural commissioner's office. You can also call the California Environmental Hotline (1-800-253-2687) to find the hazardous waste disposal site closest to you or check online at the Earth 911 website, earth911.org.

Figure 9.10

Selection guide for nonpowered and hand-operated application equipment for liquid pesticides.

	Type	Uses	Suitable formulations	Comments
	Aerosol can	Insect control on house or patio plants, small areas, cracks and crevices, and confined spaces.	Liquids must dissolve in solvent; some dusts are available.	Very convenient. High cost per unit of active ingredient.
	Hose-end sprayer	Home garden and small landscaped areas. Used for insect, weed, and pathogen control.	All formulations. Wettable powders and emulsifiable concentrates require frequent shaking.	Convenient low-cost way to apply pesticides to small outdoor areas. Cannot spray straight up. Requires backflow prevention device. Not reliably accurate in diluting the spray.
	Trigger-pump sprayer	Indoor plants, pets, and small home yard areas. Used for insect and pathogen control.	Liquid-soluble formulations best.	Low cost and easy to use.
	Compressed-air sprayer	Many commercial and homeowner applications. Can develop fairly high pressures. Used for insect and pathogen control. Often used indoors for household pest control.	All formulations. Wettable powders and emulsifiable concentrates require frequent shaking.	Good overall sprayer for many types of applications. Needs thorough cleaning and regular servicing to keep sprayer in good working condition and prevent corrosion of parts.
	Backpack sprayer	Same uses as compressed-air sprayer.	All formulations. Wettable powders and emulsifiable concentrates require frequent shaking.	Durable and easy to use. Requires periodic maintenance.

Pesticide Equipment and Calibration

Application Equipment

Most home garden pesticides are applied as a spray. Pesticide sprayers are available in many shapes, sizes, types, and prices. Select a sprayer designed to do the job you want it to do (fig. 9.10). Make sure the sprayer is easy to fill, operate, and clean. For many home and garden pesticide applications, the best choice is to purchase a ready-to-use product in a trigger-pump sprayer. For applying products that are diluted with water, the most broadly adapted application unit is the compressed-air hand or backpack sprayer with a capacity of 1 to 3 gallons. A hose-end sprayer unit is useful for large areas but has limitations and is generally not recommended. They can be used only if there is a backflow prevention device to prevent backflow into the water system. Also, these types of sprayers are not reliably accurate in diluting the spray.

Calibrating Sprayers

Pesticides in home gardens are applied mostly as spot treatments or to an entire individual plant and sprayed to runoff. The pesticide label provides the application rate, typically in ounces per gallon for most home garden insecticides and fungicides. However, the label usually does not provide information on how much spray mixture will be needed to cover noncontiguous areas or individual plants. In order to know how much pesticide product to mix up, it is useful to first spray the treatment area with water to see how much spray mixture you will need. Sometimes, however, it is necessary to spray a large contiguous area, for example, when applying herbicides to a lawn when weeds are closely spaced and cannot be easily spot-treated. Calibration will be necessary to adjust the output of the equipment to apply the desired rate of pesticide directed on the product label—typically provided in ounces per 100 square feet or 1,000 square feet. Only by calibrating correctly can you ensure the best results with the product: too much pesticide is hazardous; too little will not provide adequate pest control.

There are many ways to calibrate equipment. The preferred methods depend on the kind of equipment used. Consult directions on the equipment for proper calibration directions. The following is a basic method for calibrating compressed-air or backpack sprayers for treating areas such as lawns that cannot be easily spot-treated:

> Fill the sprayer with water and fully pressurize. Determine the delivery time by spraying water into a 16-ounce jar. Measure how much water is delivered into the jar in 30 seconds.
>
> Measure the square footage of the area to be treated. (Multiply length times width to determine the area of a rectangle or base times height divided by 2 to determine the area of a triangle.) If the area to be treated is large, divide it into sections equal to the capacity of the application equipment.
>
> Spray an area with water while operating at normal walking speed for 30 seconds. Measure the area sprayed. This tells how much area can be sprayed in 30 seconds and, therefore, the amount that is applied over that area (see the first step). For example, assume that 30 seconds of spraying delivers 8 fluid ounces and covers 100 square feet. If the total area to be treated is 1,000 square feet, the treatment will require 80 fluid ounces of diluted material (8 fl oz × 1,000 sq ft ÷ 100 sq ft). If the pesticide label calls for 3 tablespoons of pesticide for 1,000 square feet, then 3 tablespoons of pesticide must be mixed with 80 ounces of water to achieve proper spray coverage.

In general, the best spray pattern to cover an area of ground is one that gives uniform coverage with little spray overlap. The spray pattern used to apply the pesticide should be continuous and should be directed so that the applicator does not walk in the sprayed area while making the application.

The spray pattern should form an arc no more than 3 to 4 feet on either side of the operator. If good spray coverage is questionable (such as when using hose-end sprayers), cut the application rate in half and make two applications. First, apply the pesticide in an east-west direction, then make a second application in a north-south direction.

Protecting Nontarget Organisms and the Environment

Misapplication of pesticides carries serious consequences. Pesticides can cause problems when they drift or otherwise move off target. For instance, bees and other pollinators and natural enemies of pests can be killed if they are in the garden while plants are treated with certain pesticides. Fine mists of herbicides can drift to nearby areas and damage or kill landscape plants. California creeks, rivers, and oceans can be polluted with pesticides and other chemicals commonly used around our homes and gardens. These garden chemicals are not only a threat to aquatic life, but they can also affect the quality of our drinking water.

Avoid excessive use of insecticides and treat with pesticides only when there are no other effective management options. Rely on the preventive and nonchemical practices mentioned earlier in this chapter to reduce pests in most situations. When pesticides are necessary, use them sparingly and implement the practices listed below to reduce impacts to nontarget organisms and the environment. For more information about the effects of pesticides on water quality, consult the "Pesticides and Water Quality" section of the UC IPM Pest Management Guidelines, ipm.ucdavis.edu. The National Pesticide Information Center is a good source of information on pesticide hazards to people and the environment.

Select pesticides carefully

The first step is selecting a pesticide that is effective against the pest and also poses the least risks to human health and the environment. To ensure that a pesticide is effective, use the most recent IPM recommendations. Consult current and relevant UC publications such as the UC IPM Pest Management Guidelines. Refer to the list of reduced-risk pesticides provided in the section "Home Garden Pesticides," above, and to the environmentally friendly solutions at the UC IPM Pest Management Guidelines Pesticide Information website, ipm.ucdavis.edu/GENERAL/pesticides.html. Check pesticide labels for warnings regarding use near bodies of water such as streams, rivers, and lakes. Avoid the use of organophosphates and pyrethroids, which pose serious threats to aquatic invertebrates in California waterways. For more information on organophosphate and pyrethroid pesticides and their effect on aquatic organisms, refer to the UC IPM website "How Are Pesticides Affecting Water Quality?"

When possible, avoid the use of persistent pesticides. The persistence of pesticides in the environment varies primarily with the chemical characteristics of the active ingredient, the formulation, water pH, soil pH, and environmental conditions. Temperature, humidity, wind, and sunlight also affect pesticide breakdown. Usually, the greater the extremes, the sooner the pesticides are detoxified. Not all pesticides break down in the environment the same way. The longer a pesticide persists in the environment, the greater the potential for it to contaminate runoff water and move into streams and creeks. Persistent pesticides can also harm beneficials. Some persistent pesticides, such as DDT, can build up in the bodies of animals, including people. These pesticides are said to bioaccumulate; this is the reason DDT is no longer available.

Choose pesticide formulations that do not evaporate easily. Volatilization (evaporation of an active ingredient) can occur during or after application. Some products are very volatile and can move for miles under favorable conditions on air currents.

Numerous pesticide products for home gardens contain a combination of pesticides, such as combinations of insecticides

and fungicides. When possible, select formulations that contain only the specific pesticide required for managing the current pest problem. This reduces the amount of pesticides in the environment and potential pest resistance. Also, do not use products containing a combination of fertilizers and pesticides to avoid unnecessary applications of fertilizer or pesticides.

Bait stations are a good choice for ant control because the bait attracts worker ants, so they will take the product back to the nest, where the entire colony, including queens, can be killed. When properly used, baits are more effective and safer than pesticide sprays for ant control. Baits can also be used in the home garden to control snails and slugs and rodents, such as voles and gophers.

Spot spraying

Monitoring identifies diseased plants and areas in the garden where pests reside. Focusing pesticide applications in these areas rather than spraying the entire area can significantly reduce overall pesticide use. Although spot spraying can be more labor intensive, it also results in economic savings due to reduced material costs.

Figure 9.11

Honey bees may be poisoned if certain pesticides are applied while they are foraging for nectar or pollen. Avoid using materials toxic to bees when plants are in bloom. Use pesticides that have a low toxicity to bees and apply sprays early in the morning, late in the afternoon, or at night to reduce chances of killing foraging bees. *Photo:* J. K. Clark

Protect People, Pets, Wildlife, and Beneficials

Before spraying, clear all people and pets from the area. Do not spray around animal feeding dishes, bird feeders, or drinking water. Protect beneficial organisms that help control garden pests and insect pollinators, such as honey bees, by not using insecticides known to be highly toxic to them. When bees are foraging in the garden, restrict spraying to late evening or early morning, when they are not active (fig. 9.11). Do not apply insecticides when temperatures are unusually low, because residues on plants may remain toxic much longer and harm bees.

Protect Water Quality

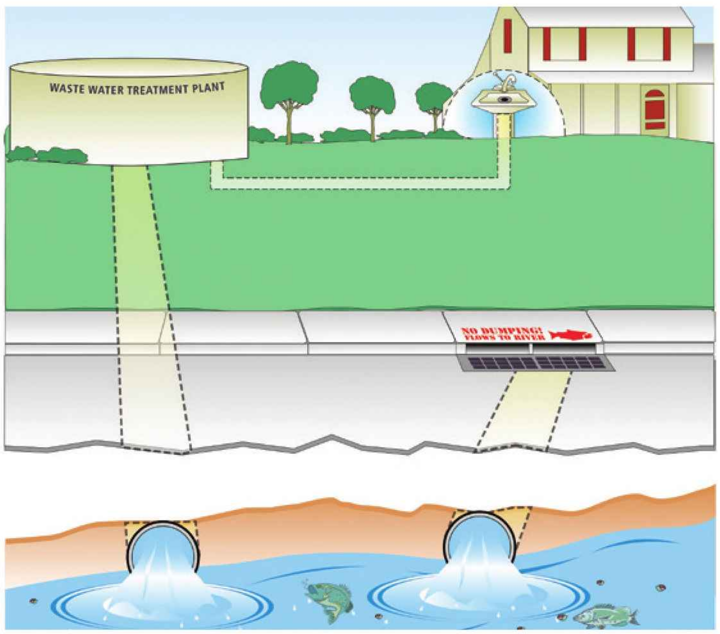
Pesticides that are used in home gardens must be applied carefully to prevent them from entering creeks and streams (fig. 9.12). Beware of potential storm sewer and groundwater contamination. Minimize runoff by designing your landscape to absorb water through permeable materials and mulches. Do not apply pesticides before irrigating (unless the product label specifies otherwise) to prevent pesticides from being washed off planted areas and into storm drains. Do not let pesticides get onto hard surfaces such as sidewalks or driveways. Do not clean pest control application equipment in a location where rinse water could flow into gutters, storm drains, or open waterways. Dispose of garden chemicals correctly. Never sweep, hose off, or pour leftover pesticides into drains or gutters. Dispose of unused products at your local household hazardous waste site.

Consider Weather Conditions When Applying Pesticides

Do not apply pesticides outdoors when rain is forecast or when it is windy; this prevents the movement of pesticides in water or on air currents. Do not apply volatile pesticides when it is windy or when

Figure 9.12

When you apply a pesticide outdoors, some of the material may be carried by rain or irrigation water through street gutters into the storm drains. If a pesticide is poured into the sink, it will end up in the sewer line and be carried to a waste treatment facility, which does not detoxify pesticides. Eventually, water carrying pesticides from storm drains and waste treatment facilities usually ends up in our creeks, rivers, and oceans.



temperatures are above 85°F. Herbicides should be applied when the wind is no more than 5 miles per hour to avoid drift onto nontarget plants. If winds come up while you are working, stop immediately.

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House Plants 10

Dennis R. Pittenger and
Ralph C. Gay

Learning Objectives

Understand the principles and environmental requirements for successfully growing house plants.

Learn which varieties and cultivars of house plants are best suited to various interiorscape climates (temperature and sunlight exposure).

Become acquainted with some of the major pests of house plants and learn basic information about how to control them.

House Plants

This chapter is designed to familiarize you with the basic principles of house plant care and provide information on the cultural requirements of many commonly grown interior foliage and flowering plants. Portions of the discussion are based on information in "House Plants" (Welsh and Cotner 2009).

Homes, apartments, and offices are typically poorly suited to the needs of plants. At the nursery, house plants are grown under nearly ideal light intensity, temperature, and other conditions. The challenges for the house plant enthusiast are to select plants that can withstand the indoor conditions of a specific location and to acquire the knowledge necessary for maintaining the chosen plants' continued growth and good health.

Selecting an Interior Foliage Plant

Use table 10.1 as a guide in selecting plants that fit the indoor gardening uses and environmental conditions where they will be placed. Just because the plant has recently come from a commercial grower does not mean that it is pest-free. Before purchasing house plants, inspect them carefully and reject any that have symptoms or signs of insect, mite, or disease infestations. Carefully inspect the underside of the foliage and the axils of leaves for insect or mite pests and possible disease problems, then choose only plants that appear to be free of pests and diseases. If possible, remove the container and look for a pest-free, healthy root ball that contains firm, white, noncircling roots. Select house plants that are sturdy, clean, well-rooted, shapely, and well-covered with leaves. Avoid plants with spindly growth and those with yellow, spotted, or chlorotic leaves, brown leaf margins, or wilted or water-soaked foliage. In addition, avoid plants with leaves that have mechanical damage. Plants that have good color with young growth are usually of high quality.

After purchase, isolate plants from other plants in your home for a few weeks and check them again as an added precaution. A plant that appeared pest-free at purchase may have had a microscopic mite infestation or may harbor insect eggs that could develop into pests.

Transporting House Plants

Extreme temperatures can damage plants. A temperature range of 50° to 85°F is recommended to avoid damage. In the summer, avoid placing plants in a closed car that is not air-conditioned because the temperature increase can injure or kill the plants in a short period. If you must travel for any distance under these conditions, shade the plants from direct sunlight while they are in the car. Otherwise, the plants could be burned by the sun shining on them through the windows, even if you use an air conditioner and the temperature in the car is comfortable.

When transporting plants at temperatures of 45°F or lower, wrap or cover them thoroughly before leaving the store. Even brief exposure to low temperatures during transport from the store to the car can severely damage tropical plants. If protective sleeves are not available, wrap plants thoroughly with a bag and place them in the passenger area of the car with the heater on. The trunks of most cars are too cold to carry plants safely in severe cold.

On an extended trip, make arrangements so that plants will not be frozen or damaged by the cold. Many foliage plants suffer from chilling injury if temperatures drop below 50°F for several consecutive hours, so maintain as warm a temperature as possible around these plants during transport.

Acclimatizing Plants

Because nurseries often grow tropical plants for production under high light intensity, these plants have "sun leaves" that are structurally different from the leaves of plants grown in shade (shade leaves). The chloroplasts of sun leaves align deep in cells and concentrate in cells away from the leaf surface, whereas the chloroplasts of shade leaves line the upper surface of cells at the leaf surface. Sun leaves are thicker, smaller in surface area, and photosynthetically less efficient than shade leaves. If these plants are placed in low light, such as in an office or room in a home, they usually drop their sun leaves and grow a new set of shade leaves, which are photosynthetically more efficient. To reduce the shock that occurs when a plant with sun leaves is placed in low light, gradually reduce the light levels to which it is exposed. This process is called acclimatization.

Before placing house plants outdoors or in an area with high light intensity, acclimatize them by gradually increasing the light intensity; reverse the process before plants are brought indoors or placed back into an area with low light. Acclimatize newly purchased plants by initially locating them in a high-light area (southern exposure) of the home and gradually reducing their hours in that area over a 4- to 8-week period before moving them to a permanent, darker location.

Environmental Factors Affecting Plant Care

Light, water, temperature, relative humidity, ventilation, nutrition, and soil are the chief factors affecting plant growth. These factors are interrelated, so if one factor is limiting, it will prevent proper indoor plant maintenance or growth. Table 10.1 provides general guidelines for light, water, and temperature requirements of many indoor foliage and flowering plants.

Light

Light is probably the most essential factor for house plant maintenance and growth and is one of the most problematic. The sunniest location inside a home often provides less light than do shady locations outside. Light is necessary for all plants because they use this energy source to photosynthesize their food. Three variables concerning light are important: intensity, duration, and quality.

Light intensity

Light intensity (the brightness of the light) influences the synthesis of plant food, stem length, leaf color, and flowering. Plants grown in light that is too low in intensity tend to be spindly and have light green leaves. Similar plants grown in very bright light are shorter, better branched, and have dark green leaves. Insufficient light is a major cause of house plant decline. On the

Table 10.1.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Abutilon hybrids	flowering maple	H	M	M-H	C,F,S
Acalypha hispida (A. wilkesiana)	chenille plant	H	M	H	S
Acanthus mollis	artist's acanthus	H	D	C-M	S
Acanthus montanus	mountain acanthus	H	D	C-M	S
Achimenes spp.	magic flower	H	M	M-H	H
Adiantum cuneatum	maidenhair fern	M	W	C-M	F
Adromischus spp.	calico hearts, leopard spots	H	D	M	D
Aechmea spp.	bromeliads	M	M	M-H	C
Aeschynanthus parasiticus	lobecup basketvine, black pagoda basketvine, black pagoda	M-H	M	M-H	H
Aeschynanthus pulcher	lipstick plant, scarlet basketvine	M	M	M-H	H
Aeschynanthus radicans	Lobbs basketvine, lipstick plant	M	M	M-H	H
Agave americana	century plant	H	D	M-H	S
Aglaonema crispum	pewter plant	L	M	H	F
Aglaonema modestum (A. commutatum, A. simplex)	Chinese evergreen	L	M	H	F,R
Aglaonema pseudo-bracteatum	golden aglaonema	L	M	H	F
Alocasia spp.	giant caladium, elephant's ear	H	M	H	S
Aloe spp.	medicine plant, aloe	V	D	M-H	D,S
Alsophila australis	Australian tree fern	H	W	H	S
Alternanthera bettzickiana	calico plant	M-H	M	M	F
Ananas comosus	pineapple	H	M	H	C,S
Anthurium alemulum	climbing anthurium	M	M	H	V
Anthurium andreanum	anthurium, spathe flower, flamingo flower	M	M	H	C,F
Aphelandra squarrosa	zebra plant	H	M	M-H	F,C
Araucaria heterophylla (A. excelsa)	Norfolk Island pine	H	M	C-M	S
Ardisia crenata (*A. crispa*)	coral berry, marlberry	M	M	M	C,F,S
Asarina erubescens	creeping gloxinia	H	M	C-M	C,H
Asparagus plumosus (A. setaceus)	bride's bouquet fern	H	M	M	F
Asparagus sprengeri (A. densiflora 'Sprenger')	asparagus fern	M	M	M	H
Aspidistra elatior	cast-iron plant	L	M	C-M	F
Asplenium nidus	bird's nest fern	M	W	M	F
Astrophytum myriostigma	bishop's cap	V	D	M-H	D
Aucuba japonica	gold-dust plant	M	D	C-M	F,S
Begonia boweri	miniature begonias	H	M	M	F,R
Begonia 'Rieger' *(B. hiemalis)*	Rieger begonia	H	M	M	F,H
Begonia rex	rex begonia	H	M	M	F,H
Begonia semperflorens	wax begonia	M-H	D-M	M	C
Billbergia zebrina	billbergia bromeliad	M	D-M	M-H	C,F
Browallia speciosa	bush violet	M-H	M	M	C
Cactus (all genera and varieties)	cactus	V	D	M-H	D,S

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Caladium spp.	caladium	H	M	H	C
Calathea makoyana	peacock plant	M	M	H	F
Calathea roseopicta	prayer plant	M	M	H	F
Calathea zebrina	zebra plant	M-H	M	H	F
Calceolaria crenatiflora	pocketbook plant	H	M	C	C
Callisia elegans	striped inch plant	M-H	M	M-H	H
Camellia spp.	camellia	L-M	D-M	C	C,S
Campanula isophylla	star-of-Bethlehem	H	M	C-M	C,H
Capsicum annuum	Christmas pepper	H-V	M	H	C
Cattleya hybrids	cattleya orchid	M	M	H	C
Cephalocereus nobilis	cylinder cactus	V	D	H	D
Cereus peruvianus 'Monstrosus'	curiosity plant	H-V	D	M-H	D
Ceropegia woodii	string of hearts; rosary vine	H	M	H	H
Chamaedorea elegans (Neanthe bella)	parlor palm	L	M	M-H	F,R
Chamaedorea erumpens	bamboo palm	L	M	M-H	F,S
Chamaerops humilis	European fan palm	H	D-M	M-H	S
Chlorophytum bichetii	False lily turf; St. Bernard's lily	H	D	M-H	H
Chlorophytum comosum 'Variegatum'	spider plant	H	D	M-H	H
Chrysalidocarpus lutescens	areca palm	M	M	H	F,S
Chrysanthemum morifolium	chrysanthemum	V	M	C-M	C
Cissus antarctica	kangaroo vine	H	M	M-H	H,R,V
Cissus discolor	rex begonia vine	M	D	M	H,V
Cissus rhombifolia	grape ivy	M	D-M	M	H,V
Cissus rotundifolia	Arabian wax cissus	M	D-M	M	H
Citrus spp.	citrus (grapefruit, lemon, orange)	V	M	M-H	C,S
Clerodendrum thomsoniae	bleeding-heart vine	H	M	M-H	C,F,H,V
Clivia miniata	Kaffir lily	M	D	M-H	C,F
Clusia rosea	autograph tree	M	D	M-H	F,S
Codiaeum variegatum	croton	V	D	H	F,S
Coffea arabica	Arabian coffee plant, coffee tree	M	M	H	R,S
Coleus rehneltianus 'Trailing Queen'	trailing coleus	H	M	M-H	H
Columnea gloriosa	goldfish vine	M	M	M-H	C,H
Columnea microphylla	small-leaved goldfish vine	M	M	M-H	C,H
Commelina communis aurea-striata	variegated widow's tear	M-H	M	C-M	H
Convallaria majalis	lily-of-the-valley	H	M	C-M	C
Cordyline terminalis	hawaiian ti plant	M	M	H	F,S
Cordyline terminalis minima 'Baby Ti'	dwarf ti plant	M	M	H	R
Crassula argentea	jade plant	H-V	D	H	D,F
Crassula lycopodioides	toy cypress, watch chain; rat tail plant	V	D	H	D
Crassula rupestris	rosary vine	V	D	H	D,H
Crocus spp.	crocus	H	M	C	C
Crossandra infundibuliformis	firecracker flower	M	M	M-H	C,F

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Cryptanthus spp.	dwarf rose-stripe, earth star, dwarf bromeliad	H	D-M	M-H	C,R
Cyanotis kewensis	teddy bear vine	M	M	M-H	H
Cyanotis somaliensis	pussy ears	M	M	M-H	H
Cycas revoluta	sago palm	M	D-M	M-H	F,S
Cyclamen spp.	cyclamen	H	M	C	C
Cymbalaria muralis	Kenilworth ivy	M	M	C-M	H
Cymbidium hybrids	cymbidium orchid	M	M	C-M	C
Cyperus alternifolius	umbrella plant	M	W	M-H	S
Cyrtomium falcatum	Japanese holly fern	L-M	M	C-M	F
Dahlia pinnata	dahlia	H	M	H	C
Davallia spp.	rabbit's foot fern, squirrel's foot fern	L-M	M	M-H	H
Dichorisandra reginae	queen's spiderwort	M	M	M	C,F
Dieffenbachia amoena	spotted dumbcane	M	D	M-H	S
Dieffenbachia 'Exotica'	dumbcane	M	D	M-H	F,S
Dionaea muscipula	venus fly trap	M	M-W	C-M	F
Dizygotheca elegantissima	false aralia	H	M	H	R,S
Dracaena deremensis 'Janet Craig'	green dracaena	M	M	H	F,S
Dracaena deremensis 'Warneckii'	white-striped dracaena	M	D-M	H	F,S
Dracaena fragrans var. *massangeana*	corn plant	L	M-W	H	F,S
Dracaena marginata	dragon tree	M	D-M	H	F,S
Dracaena sanderiana	ribbon plant, lucky bamboo	M	M	H	F,R,S
Dracaena surculosa (D. godseffiana)	gold-dust plant	M	M-W	H	F,R,S
Echeveria spp.	hen-and-chicken	M	D	H	D
Echinocactus grusonii	golden barrel cactus	H-V	D	M-H	D
Echinocactus micromeris	button cactus	H-V	D	M-H	D
Echinocactus pectinatus var. *neomexicanus*	rainbow cactus	H-V	D	M-H	D
Echinocactus reichenbachii	lace cactus	H-V	D	M-H	D
Epiphyllum hybrids	orchid cactus	H	M	M	H
Epipremnum aureum	pothos	L	D-M	H	F,H
Episcia cupreata	flame violet, ember lace episcia	M	M	H	G,H
Episcia cupreata 'Amazon'	Amazon flame violet	M	M	H	G,H
Episcia cupreata 'Chocolate Soldier'	carpet plant	M	M	H	G,H
Episcia cupreata 'Emerald Queen'	emerald queen episcia	M	M	H	G,H
Episcia cupreata 'Silver Sheen'	silver sheen episcia	M	M	H	G,H
Episcia dianthiflora	lace flower vine	M	M	H	H
Episcia 'Moss Agate'	Panama episcia	M	M	H	H
Eranthemum nervosum (E. pulchellum)	blue sage	M	M	M	C,F
Erica gracilis	heather	H	M	C-M	C
Eriobotrya japonica	Japanese loquat	H-V	D-M	H	F,S
Euonymus japonica	spindle tree	H	D	C	F,R
Euphorbia lactea	candelabra cactus	M	D	M-H	D,F

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Euphorbia lactea cristata	crested euphorbia, frilled fan	M-H	D	M-H	D
Euphorbia mammillaris	corncob plant	M	D	M-H	D,H
Euphorbia milii	crown-of-thorns	H	D	M-H	C,F,H
Euphorbia pulcherrima	poinsettia	V	D-M	M-H	C
Exacum affine	Persian violet, exacum	M	M	C	C
Fatshedera lizei	botanical wonder, fatshedera	M	M	M	S
Fatsia japonica (Aralia sieboldii, A. japonica)	Japanese aralia	M	M	C-M	S
Faucaria tigrina	tiger jaws	V	D	M	D
Ficus benjamina (*F. benjamina* 'Exotica' or 'Midnight')	weeping java fig	M-H	M	M-H	F,S
Ficus diversifolia (F. deltoidea)	mistletoe fig	M	M	M-H	F,R,S
Ficus eburnea	ivory fig	M	M-W	M-H	S
Ficus elastica 'Decora'	rubber plant	M	M	M-H	F,S
Ficus elastica 'Variegata'	variegated India rubber tree	M-H	M	M-H	F,S
Ficus lyrata	fiddleleaf fig	M	M	M-H	S
Ficus radicans	climbing fig	L-M	M	C-M	F,G
Ficus repens var. *pumila*	creeping fig	L-M	M	C	F,G
Ficus repens var. *pumila* 'Minima'	dwarf creeping fig	L-M	M	C	F,G,R
Ficus retusa nitida	India laurel	L	D	H	F,S
Ficus triangularis	triangleleaf fig	M	M	M-H	F
Fittonia verschaffeltii	silver nerve plant	M	M	H	G,H,R
Fittonia verschaffeltii var. *pearcei*	snake skin plant	M	M	H	G,H
Fuchsia spp.	fuchsia	V	M	M	H
Fuchsia triphylla 'Gartenmeister Bohnstedt'	honeysuckle fuchsia	V	M	M	H
Fuchsia var. 'Swingtime'	swingtime fuchsia	V	M	M	H
Fuchsia var. 'Jubilee'	jubilee fuchsia	V	M	M	H
Gardenia jasminoides	gardenia	V	M	H	C,F
Gasteria liliputana	ox tongue; liliput	M-H	D	M	D
Guzmania lingulata	scarlet star; orange star	M	D-M	C-M	C,F
Gynura aurantiaca	velvet plant, purple passion plant, purple velvet plant	M	M	M-H	F,H
Haemanthus coccineus	blood lily	V	M	M	C
Hatiora salicornioides	drunkard's dream	H	M	M	H
Haworthia spp.	zebra haworthia, wart plant, pearl plant	M	D	M	D
Hedera helix	English ivy	L-M	M	C-M	F,G,H
Hedera helix 'Hahn's Variegated'	variegated Hahn's English ivy	M	M	C-M	F,G,H
Hedera helix 'Ivalace'	Ivalace English ivy	L-M	M	C-M	F,G,H
Hedera helix 'Needlepoint'	needlepoint English ivy	L-M	M	C-M	F,G,H,R
Hemigraphis colorata	red ivy	M	M	H	G,H
Hemigraphis exotica	waffle plant	M	M	H	G,H
Hibiscus rosa-sinensis	Chinese hibiscus	V	M	M	C,F
Hippeastrum vittatum	amaryllis	H	M	M	C
Howea forsterana	kentia palm	L-M	M	M-H	S

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Hoya australis	porcelain flower	M	D-M	M	H
Hoya bella	miniature wax plant	M	D-M	M	H
Hoya carnosa	wax plant, Hindu rope plant	M	D-M	M	H
Hoya carnosa 'Compacta'	compact wax plant	M	D-M	M	H
Hoya carnosa 'Exotica'	exotic wax plant	M	D-M	M	H
Hoya carnosa 'Krinkle Curl'	Hindu rope plant	M	D-M	M	H
Hoya carnosa 'Tri-color'	variegated wax plant	M-H	D-M	M	H
Hoya imperialis	honey plant	M	D-M	M	H
Hoya keysi	pubescent wax plant	M	D-M	M	H
Hoya longifolia shepherdii	shepherd's wax plant	M	D-M	M	H
Hoya motoskei	spotted wax plant	M-H	D-M	M	H
Hoya purpureo-fusca	silver pink wax plant	M	D-M	M	H
Hyacinthus orientalis	hyacinth	H	M	C	C
Hydrangea macrophylla	hydrangea	H	M	C	C
Hylocereus undatus	night blooming cereus	V	M	M-H	C,H
Hypocyrta nummularia (Alloplectus nummularia)	goldfish plant	M	M	H	C,H
Hypoestes sanguinolenta	polka-dot plant	M	M	H	C
Impatiens spp.	impatiens	H	M	H	C
Ipomoea batatas	sweet potato	V	M	H	F,H
Jasminum spp.	jasmine	V	M	C	C,F,V
Justicia brandegeeana (Beloperone guttata)	shrimp plant	H	D	H	C
Kalanchoe blossfeldiana	kalanchoe, panda plant	M-H	D-M	M	C,F
Kalanchoe gastonis-bonnieri	donkey ears; life plant	M-H	D-M	M	C,H,S
Kalanchoe manginii	mangin kalanchoe, chandelier plant	M-H	D-M	M	C,H
Kalanchoe pubescens	jinglebells kalanchoe	M-H	D-M	M	C,H
Kalanchoe tomentosa	panda plant	M-H	D-M	M	H
Kalanchoe uniflora	miniature kalanchoe	M-H	D-M	M	H
Lantana camara	lantana, yellow sage	H-V	D-M	H	G,H
Lantana montevidensis	trailing lantana	H-V	D-M	H	C,G,H
Leea coccinea	West Indian holly; leea	M	M	M	C,F,S
Ligustrum japonica	wax-leaf privet	M-H	D-M	M	S
Ligustrum lucidum	glossy privet	M	D-M	M	S
Lilium longiflorum	Easter lily	H	M	C-M	C
Lithops spp.	living stones	V	D	H	D
Mammillaria bocasana	powder-puff cactus	H-V	D	M	D
Mammillaria elongata	lace mammillaria, golden star cactus	H-V	D	M	D,H
Mammillaria fragilis	thimble cactus	H-V	D	M	D
Maranta leuconeura	prayer plant	M	M	H	F,R
Mikania ternata	plush vine	M	M	H	H,V
Mimosa pudica	sensitive plant	H	M	H	F,S
Monstera deliciosa	swiss cheese plant, split-leaf philodendron	L-M	M	H	S
Muehlenbeckia axillaris	wire vine	M-H	D-M	H	G,H

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Muscari spp.	grape hyacinth	H	M	C	C
Narcissus pseudonarcissus	daffodil	L	D	C	C
Nautilocalyx lynchii	coral plant	M	M	M	C,F,R
Neoregelia carolinae tricolor	tricolor bromeliad	M	D-M	H	C
Nepenthes spectabilis	pitcher plant; fingernail plant	M	M-W	M-H	F
Nephrolepis exaltata 'Bostoniensis'	Boston fern	M	M	C-M	F,H,R
Nephrolepis exaltata 'Fluffy Ruffles'	fluffy ruffles fern	M	M	C-M	F,H,R
Nephrolepis exaltata 'Rooseveltii'	tall featherfern	M	M	C-M	F,H,R
Nerium oleander	oleander	H	D-M	M	C,F,S
Nicotiana affinis	flowering tobacco	H	D	H	C,H
Nolina recurvata (Beaucarnea recurvata)	pony tail palm	M	D	H	F,S
Opuntia erectoclada	dominoes, pincushion cactus	V	D	M	D
Opuntia microdasys	bunny ears	V	D	M	D
Opuntia vilis	dwarf tree opuntia	H	D	M	D
Oxalis spp.	oxalis, shamrock plant	M	M	M	F
Pachystachys coccinea	lollipop plant; cardinal's guard	V	M	M-H	C,F
Pandanus veitchii	screw pine	M	D-M	H	S
Paphiopedilum hybrids	lady-slipper orchid	M	M	C-M	C
Passiflora spp.	passion flower	V	M	H	C,F,H,V
Pelargonium × fragrans	scented geranium	V	D-M	M-H	F,H,P
Pellionia caperata	emerald ripple peperomia	L	D	M	F,H,R
Pellionia cubensis	Cuban pepperface	L	D	M	F,H
Pellionia glabella 'Variegata'	variegated wax privet peperomia	H	W	M	H
Pellionia metallica	metallic peperomia	M	M	M	H
Pellionia obtusifolia	oval leaf peperomia	M	M	M	H
Pellionia pulchra	satin pellonia	M	M	M	G,H
Pellionia repens (P. daveauana)	trailing watermelon vine, trailing watermelon begonia	M	M	M	G,H
Pellionia scandens	philodendron peperomia	M	M	M	G,H
Peperomia sandersii	watermelon peperomia	M	M	M	F,R
Peristrophe hyssopifolia 'Aurea-Variegata'	marble-leaf	M	M	M	H
Persea spp.	avocado	H-V	M	M	F,S
Petunia hybrida	cascade petunia	V	M	H	C
Phalaenopsis hybrids	phalaenopsis orchid	M	D-M	M	C
Philodendron cordatum (P. scandens)	heartleaf philodendron	L-M	M	M-H	G,H,V
Philodendron domesticum 'Hastatum'	elephant ear philodendron	M	M	H	S
Philodendron elongatum	philodendron	M	M	M-H	S
Philodendron giganteum	giant philodendron	M	M	M-H	S
Philodendron mandaianum	philodendron	M	M	M-H	S
Philodendron micans (P. scandens micans)	velvetleaf philodendron	M	M	M-H	H

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Philodendron oxycardium (P. scandens oxycardium)	common philodendron	L	D	M-H	G,H,V
Philodendron panduriforme	fiddleleaf philodendron	M	M	M-H	S
Philodendron selloum	selloum philodendron	M	M	M-H	S
Philodendron wendlandii	philodendron	M	M	M-H	S
Phoenix roebelenii	dwarf date palm	M-H	D-M	M-H	S
Pilea cadierei	aluminum plant	M	M	M	F
Pilea cadierei 'Minima'	aluminum plant	M	M	M	F,R
Pilea depressa	miniature pilea, baby's tears	M	M	M	F,H,R
Pilea microphylla	artillery plant, artillery fern	M	M	M	F,R
Pilea nummulariifolia	creeping charlie	M	M	M	G,H,R
Pisonia grandis 'Tricolor'	bird catcher tree	H	M	H	F,S
Pittosporum tobira	mock orange	H	D	C-M	F,S,R
Platycerium alcicorne	staghorn fern	M	M-W	M-H	H
Plectranthus australis	Swedish ivy	M	M	M	H
Plectranthus coleoides 'Marginatus'	candle plant	M	M	C-M	H
Plectranthus oertendahlii	prostrate coleus	M	M	M	H
Plectranthus purpuratus	moth king	M	M	M	H
Plectranthus tomentosus	succulent coleus	H	M	M	H
Pleomele reflexa	green pleomele; song of India	M	M-W	M	F,S
Pleomele thalioides	lance dracaena	M	M	M	F
Podocarpus macrophillus	yew tree; podocarpus	H	M	M	F,R
Polypodium aureum	hare's foot fern	M	M	M-H	F,H
Polyscias guilfoylei	parsley aralia	M	M	H	F,S,R
Polyscias paniculata 'Variegata'	jagged-leaf aralia	M	M	H	S
Portulacaria afra	elephant bush	H-V	D	M	D,H
Portulacaria afra 'Variegata'	rainbow bush	H-V	D	M	D,H
Primula malacoides	fairy primrose	H	M	C	C
Primula obconica	German primrose, top primrose	H	M	C	C
Pteris spp.	brake or table ferns	M	M	M-H	R
Radermachera sinica	China doll, emerald tree, Asian bell tree (dwarf)	H	W	H	F,S
Rebutia kupperiana	scarlet crown cactus	H	D	H	D
Rebutia minuscula	red crown cactus	H	D	H	D
Rhapis excelsa	lady palm; bamboo palm	M	M	M-H	S
Rhipsalis capilliformis	old man's beard cactus	H	D-M	M-H	H
Rhipsalis baccifera (B. cassutha)	mistletoe cactus	H	D-M	H	H
Rhipsalis houlletiana	snowdrop cactus	V	D	H	H
Rhipsalis paradoxa	chain rhipsalis	V	D	H	H
Rhipsalis pentaptera	fivewing rhipsalis	V	D	H	H
Rhipsalis trigona	triangle rhipsalis	V	D	H	H
Rhododendron spp.	azalea	H	M	C	C
Rhoeo discolor	Moses-in-the-cradle	M	M	M-H	F
Rosa chinensis var. *minima*	miniature rose	V	M	C	C

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Rosmarinus officinalis	rosemary	V	D	M	F
Ruellia makoyana	monkey plant; ruellia	M	M	M	H
Saintpaulia spp.	African violet; all cultivars	H-V	M	H	R
Salvia splendens	scarlet sage	V	M	M-H	C,F
Sansevieria trifasciata	snake plant	L	D	M-H	F
Saxifraga sarmentosa	strawberry begonia, strawberry geranium	V	D-M	M	G,R
Schefflera actinophylla (Brassia actinophylla)	schefflera	M	M	M	S
Schlumbergera bridgesii (Zygocactus truncatus)	Christmas cactus	H	M	M	H
Schlumbergera gaertneri (Hatiora gaertneri, Rhipsalis gaertneri)	Easter cactus	H	M	M	H
Scindapsus aureus (S. pictus)	devil's ivy	M	M	M-H	G,H
Sedum acre	golden carpet, gold moss	H	D-M	M-H	D
Sedum adolphi	golden sedum	H	D-M	M-H	D
Sedum dasyphyllum	golden glow	H	D-M	M-H	D
Sedum lineare	carpet sedum	H	D-M	M-H	D
Sedum morganianum	burro's tail	H	D-M	M-H	D,H
Sedum multiceps	miniature Joshua tree	H	D-M	M-H	D
Sedum × rubrotinctum	Christmas cheer	H	D-M	M-H	D
Sedum spp. (any sp. not listed here)	stonecrop	H	D-M	M-H	D
Sedum stahlii	coral beads	H	D-M	M-H	D
Selaginella emmeliana	sweat plant	M	M	M	R
Selaginella kraussiana	creeping club moss	M	M	M	R
Selaginella lepidophylla	resurrection plant	L-M	D-M	M	F,R
Senecio cruentus	cineraria	H	M	C-M	C
Senecio jacobsenii	weeping jade; trailing jade	H	M	M	H
Senecio macroglossus 'Variegatum'	variegated wax ivy	M	M	M	H
Senecio mikanioides	German ivy	M	M	M	H
Senecio rowleyanus	string of pearls	M	D	M	H
Setcreasea purpurea	purple heart	M	D-M	H	H
Sinningia spp.	gloxinia	M-V	M-W	M	R
Solanum pseudocapsicum	Jerusalem cherry	H	D-M	C	C
Soleirolia soleirolii (Helxine soleirolii)	baby's tears	M	M-W	C-M	F,R
Solenostemon scutellaroides (Coleus blumei, C. hybridus)	coleus	H-V	M	M-H	C
Spathiphyllum 'Mauna Loa'	peace lily; white flag	M	D-M	M-H	F
Stapelia gigantea	starfish flower, giant toadplant	V	D	H	H
Stenotaphrum secundatum variegatum	variegated St. Augustinegrass	H-V	M	H	H
Strelitzia reginae	bird of paradise	M-H	M	M	S
Streptocarpus spp.	Cape primrose; false African violet	H	M	C-M	H
Strobilanthes dyerianus	Persian shield	M	M	C-M	F
Syngonium podophyllum	arrowhead vine, nephthytis	L	M	M-H	R

Table 10.1. cont.

CULTURAL REQUIREMENTS AND USES FOR SELECTED PLANTS GROWN AS HOUSE PLANTS

Scientific name	Common name	Light requirement*	Water requirement†	Temperature requirement‡	Use§
Tagetes spp.	marigold	V	M	M	C
Thunbergia alata	black-eyed susan	H	M	M	C
Thymus vulgaris	thyme	H	D-M	M	F
Tolmiea menziesii	piggyback plant	H	M	C-M	F
Tradescantia albiflora	wandering Jew	M	D-M	C-M	G,H
Tradescantia albiflora 'Albovittata'	giant white inch, wandering Jew	M	D-M	C-M	G,H
Tradescantia sillamontana	white velvet; white gossamer	M	D-M	M	G,H
Trifolium repens minus	shamrock plant	M	M	M	F
Tulipa spp.	tulip	H	M	C	C
Vanilla fragrans 'Marginata'	vanilla	H	M	M	V
Verbena hortensis	verbena	H	M	M	C,H
Vinca major 'Variegata'	periwinkle	M	D-M	M	G,H
Viola tricolor	pansy, Johnny-jump-up	H	M	C	C
Vriesea splendens	flaming sword	M	M	M-H	C,F
Yucca spp.	yucca	L	D	M-H	F,S
Zantedeschia spp.	calla lily	H	M-W	C-M	C,F
Zebrina spp.	wandering Jew	M	M	M	G,H
Zinnia elegans	zinnia	H	M	H	C

Source: Adapted from Poole and Pittenger 1980, pp. 16–19; Welsh and Cotner 1989.

Notes:

*Light levels are for maintenance purposes only. They may not permit satisfactory growth. Light requirements are for 8 to 12 hrs daily:
L = low (25–50 foot-candles); M = medium (50–100 foot-candles); H = high (100–200 foot-candles); V = very high (200–400 foot-candles).

†Optimal soil moisture conditions and general watering schedules for the warmer months of the year or when plant is actively growing: D = dry (may need watering only every 10 to 14 days or longer, allow soil to dry before watering); M = moist (may need watering at least once per week, soil may dry slightly between waterings but plant may die if soil dries completely, do not allow soil to remain saturated); W = wet (plant needs watering every few days and soil should be moist but not saturated at all times).

‡Temperature ranges in which plant will perform best indoors: C = cool (50°–60°F during the day and 45°–55°F at night); M = medium (60°–70°F during the day and 55°–60°F at night); H = high (70°–80°F during the day and 65°–70°F at night).

§Indoor gardening use(s) the plant is best suited for: C = colorful flowers, striking colorful foliage, or holiday plant; D = desert dish garden; F = general foliage plant grown primarily for its attractive leaves; G = low creeping groundcover in large interior planters; H = hanging baskets or similar container; R = tropical terrariums; S = large container-grown specimen plant; V = vine or trailing plant trained to a totem pole or similar support.

other hand, if the light intensity is too high, the foliage of some house plants can become pale, sunburned, turn brown, and die. Use a photo light meter to accurately measure indoor light intensity.

The intensity of indoor light a plant receives depends greatly on the nearness of the light source to the plant. Light intensity decreases rapidly as you move away from the light source. The exposure of the windows in your home affects the intensity of natural sunlight indoors. Southern exposures have the most intense light; eastern and western exposures receive about 60% of the intensity of southern exposures; and northern exposures receive 20%. Other factors that can influence the intensity of light penetrating a window are the presence of draperies, energy-absorbing or reflective coatings applied to or incorporated in the glass, shade trees outside the window, weather, seasons of the year, shade from other buildings, and the cleanliness of the window. Reflective (light-colored) surfaces inside the home or office increase the intensity of light available to plants. Dark surfaces decrease light intensity.

House plants can be classified according to their general light requirements: very high, high, medium, and low. In general, low-light locations are more than 6

feet from windows and receive no direct light. Medium-light locations are areas roughly 3 to 6 feet from brightly lit windows facing south, east, or west. High-light areas are within 3 feet of such windows. Most house plants require medium or high light to remain aesthetically appealing (see table 10.1). The distances noted above will be reduced if one or more factors discussed earlier that influence the light intensity penetrating a window are present.

Light duration

Day length, or the duration of light received by plants during a 24-hour period, is also important, especially to flowering and holiday plants that are photoperiodic (sensitive to light duration). Poinsettia, kalanchoe, Christmas cactus, and chrysanthemum initiate flowers when day length is relatively short (less than 12 hrs of light). Most flowering and foliage house plants are indifferent to day length. Compensate for low light intensity by increasing the duration of the plant exposure to the light, as long as the plant is not adversely sensitive to day length in its flowering response. Increased hours of low-intensity light may allow the plant to photosynthesize enough food to survive and grow normally.

Light quality

Light quality refers to the color of the light, either sunlight or artificial light. Incandescent or fluorescent lights can provide supplemental lighting. Incandescent lights produce a great deal of heat and are not very efficient users of electricity. If artificial lights are the only source of light for growing plants, light quality must be considered. For vegetative growth and photosynthesis, plants use blues and reds most efficiently. Incandescent lights produce mostly red, and some infrared light, but very little blue. Fluorescent lights vary according to the phosphorus coating used by the manufacturer. Cool-white lights produce mostly blue light and are low in red light. Foliage plants grow well under cool-white fluorescent lights, which are cool enough to position quite close to plants. The higher amount of infrared light required by flowering plants can be supplied by incandescent lights or special horticultural-type fluorescent lights that produce higher levels of blue and red.

Water

Overwatering and underwatering account for a large percentage of house plant problems and losses (see table 10.2). One of the most common questions home gardeners ask is, “How often should I water my plants?” There is no simple answer. Differences in species’ water-use rates, potting media, and environment influence water needs. With the exception of relatively few plant species, two important rules about proper watering techniques are never to permit the soil medium to dry out completely between waterings and never to allow plants to stand in water for an extended time. Roots may die and foliage may wilt in both situations. In dry soil, roots can dry out and lose their ability to absorb water and nutrients. Conversely, soil that is too wet for too long can kill roots because it encourages the growth of root pathogens and excludes air (oxygen), which roots need for respiration and growth.

Table 10.1 provides watering guidelines for many house plants. As a general guide, a plant needs water when the top 1 inch of soil is dry in pots less than 6 inches in diameter and the top 2 inches are dry in larger pots. Insert your index finger to the 1- to 2-inch depth and feel the soil to check for moisture. If the soil feels damp, do not water. Repeat the test until the soil is barely moist at the 1- to 2-inch depth. Exceptions to this rule are the plants in table 10.1 whose watering requirements are listed as “dry” or “wet.” When testing the soil, pay attention to the soil condition. If your index finger cannot penetrate 1 to 2 inches deep, the plant needs a more porous soil mix or may be root-bound.

Always water until a little water runs

out of the bottom of the pot. Apply about 10 to 20% more water than the container media can hold. This technique serves two purposes. First, it washes all the excess salts (fertilizer residue) from the soil. Second, it guarantees that the entire pot and root system receive thorough watering. Do not let the pot stand more than several minutes in the water that has run out. Empty the saucer. See the discussion below on soluble salts to learn more about proper watering.

Water quality is not usually a problem when ordinary tap water is used on house plants. The chlorine and fluorine that are often added to potable water do not harm plants. However, water that is artificially softened should not be used to water house plants regularly. Similarly, water containing boron should not be used on house plants or any container-grown plants.

Temperature

Most house plants grow and perform satisfactorily at normal household temperatures. However, many flowering house plants perform best at nighttime temperatures of 55° to 60°F. A good rule of thumb is to keep the night temperature 10° to 15°F lower than the day temperature if possible. The lower night temperature induces physiological recovery from moisture loss, intensifies flower color, and prolongs flower life.

Excessively low or high temperatures may cause spindly appearance, foliage damage, leaf or flower drop, and general plant decline. Avoid putting plants in areas with widely fluctuating temperatures, such as on top of television sets. Move plants from windowsills and doorways in cold winter months. A southern exposure is the warmest; eastern and western exposures are less warm; and a northern exposure is the coolest. Table 10.1 gives temperature requirements of selected house plants.

Relative Humidity

Atmospheric humidity is commonly expressed as a percentage of relative humidity, which is the ratio of the current amount of water vapor held by the air to the highest amount that it could possibly hold. It is difficult to significantly increase relative humidity in the vicinity of house plant containers. When relative humidity is very low for prolonged periods, attaching a humidifier to the heating or ventilating system in the home, grouping plants close together, or placing gravel trays in which an even moisture level is maintained under the plant containers are sometimes used to increase humidity around the plants. However, the effectiveness of these practices varies widely and can be inconsequential. Spraying mist occasionally on the foliage of plants does not significantly affect relative humidity.

Ventilation

House plants, especially flowering ones, can be very sensitive to cold or hot drafts. Do not place them directly in front of forced air vents or near doors that frequently open to the outside of a building. Drafts and forced air dry house plants rapidly and may cause cold or heat damage.

Fertilization

House plants primarily need fertilizers containing three major plant nutrient elements: nitrogen (N), phosphorus (P), and potassium (K). Fertilizer products for house plants are available in many different combinations of nitrogen, phosphorus, and potassium along with other essential plant nutrients under a multitude of product names. The label on each product indicates the percentage by weight of available elemental nitrogen, phosphate, and potash (potassium). Commercial fertilizers used for house plants are sold as liquids, granules, crystals, and tablets that are mixed with water for application, or as slow-release crystals, pellets, and spikes that are placed on the soil surface or incorporated into the soil. Each should be used according to the instructions on the package label or diluted even more. Do not overfertilize, which can increase

soluble salts and possibly kill house plants.

The frequency of fertilizer application depends on the purpose of the plant and the formulation of fertilizer used. If the plant is a nonflowering foliage plant and the desire is to keep it healthy at a given size, fertilization may be necessary every 4 to 6 weeks. However, if the plant is a flowering one or if the desire is to have the plant grow vigorously, fertilizer may be necessary every 1 to 2 weeks. Use of slow-release fertilizers extends the above intervals by a factor of 2 to 4. If light, soil moisture, or other factors are limiting to plant growth, adding fertilizer will not overcome them. When applying liquid forms of fertilizer, make sure that some solution runs out of the bottom of the pot. This technique prevents the buildup of salts (excess fertilizer) and reduces the risk of injuring roots and foliage.

Soluble Salts

Soluble salts may accumulate on the top of the soil, forming a yellow or white crust. A ring of salt deposits may form around the pot at the soil line or around the drainage hole. Salts may also build up on the outside of clay pots. In house plants, signs of excess soluble salts in the soil include reduced growth, brown leaf tips, dropping of lower leaves, small new growth, dead root tips, and wilting (see table 10.2).

The level of salts that causes injury varies with the species of plant and how it is grown. A house plant may be injured by salts at a very low concentration, but the same plant growing in a greenhouse where watering is well managed may tolerate salts at high levels. Some nurseries and retail plant outlets leach plants (see below) to remove excess salts before the plant is sold. To be safe, leach newly purchased plants the first time they are watered.

The best way to prevent soluble salt injury is to stop the salts from building up by proper water and fertilizer management. As discussed earlier, when watering, allow some water to drain through the container, then empty the saucer. Do not allow the pot to sit in water. If the soil absorbs the drained water, it will reabsorb the salts that had been washed out. Be judicious with fertilizer application and follow the guidelines discussed above.

House plants should be leached at least every 3 to 4 months. To leach plants, pour excess water on the soil and let it drain completely. The amount of water used for leaching should equal twice the volume of the pot. Keep the water running through the soil to wash out the salts. If a layer of salts has formed a crust at the soil surface, remove the salt crust before leaching. However, do not remove more than about ¼ inch of soil. It is best not to replace soil removed from the top of the pot. If the soluble salt layer appears to be extremely thick, repot the plant.

pH

The pH of commercially prepared potting soil is usually slightly to moderately acidic, which is acceptable to most house plants. Rarely is the pH too low (acidic) or too high (alkaline) to maintain house plants. If you suspect that the pH of the soil a plant is currently growing in is too high or low, wash the soil from the root system and repot the plant in new potting soil.

Growing Media

Potting soil or growing media for plants must be of good quality and meet certain performance criteria. The chemical and physical properties of a potting soil determine its performance. To sustain plant growth, the medium must hold large quantities of water in a limited volume and yet maintain a high volume of aeration. Because soil in a container does not behave the same as soil in the field, potting soil is typically formulated with a high percentage of bulky organic materials such as bark, wood chips, peat, coir (fiber from coconut shells), or compost. These materials hold varying amounts of nutri-

ents and water, and they also create pockets of air in the medium. Media usually contain additional nonorganic materials such as sand, vermiculite, or perlite, which provide additional aeration and structure. Quality potting soil should be low in soluble salts, slightly acidic (pH 5–6.5), and capable of holding essential nutrients for plant growth.

It is more practical to use a commercially prepared potting soil than to buy ingredients and formulate your own. However, potting soils sold though retail garden supply outlets vary widely in their performance as growing media. In California, manufacturers are required to label the product with the names of the ingredients in decreasing order of volume. Unfortunately, there are no consistent relationships between the physical and chemical properties of a potting soil and its ingredients list. The following recommendations increase the chances of success in selecting and using commercial potting soil:

Select mixes high in bark, coir, forest materials, or sphagnum peat with vermiculite or perlite. Mixes that include a wetting agent are also desirable, but the use of such products may not be noted on the label.

Thoroughly leach any potting soil before placing seed or plant material in the mix. Leaching reduces soluble salts to acceptable levels in most mixes.

To replace leached nutrients and those taken up by the plants, fertilize with a soluble fertilizer according to the manufacturer's directions about 2 to 4 weeks after plants are growing in new potting soil or after several waterings.

Containers

A container should be large enough to provide room for soil and roots, have sufficient headroom for proper watering, provide good bottom drainage, and be an aesthetically pleasing shape and size in relation to the plant it holds. (Headroom is the amount of space between the soil level and the top of the pot, which allows for watering a plant.) Small containers should have at least one drainage hole, and large containers should have proportionally more holes. Containers may be made of ceramic, plastic, fiberglass, wood, aluminum, copper, brass, glass, or many other materials. Table 10.1 lists house plants suitable for many types of containers, including hanging baskets, tropical terraria, large decorative containers for specimen plants, and desert dish gardens.

Clay and ceramic containers

Unglazed and glazed porous clay pots with drainage holes are sometimes still used by commercial plant growers, although they are no longer the standard. Although easily broken, clay pots provide excellent aeration for plant roots and are considered by some professional horticulturists and home gardeners to be the best type of container for a plant. Clay pots, unlike plastic ones, absorb and lose moisture through their walls. The greatest accumulation of roots in any container is frequently next to the walls of the pot.

Ceramic pots are sometimes glazed on both the outside and inside. Frequently, they are designed without adequate drainage holes. Use them only as a decorative sleeve to hide a well-drained but unattractive container. Avoid small novelty containers because they have little room for soil and roots and are largely ornamental.

Plastic, fiberglass, and resin containers

Plastic, fiberglass, and resin containers are usually quite light and easy to handle. They have become the standard in recent years because they are relatively inexpensive and can be made quite attractive in shape and color, making them ideal for large decorative containers. These pots are easy to sterilize or clean for reuse, and because they are not as porous as clay pots, they need less-frequent watering and tend to accumulate fewer salts. As with glazed ceramic pots, some resin and fiberglass

pots are designed without adequate drainage holes. Drainage holes can usually be created in these containers with an electric drill fitted with a ½- to 1-inch-diameter boring bit. Alternately, such a container can be used as a decorative sleeve to hide an unattractive but well-drained container.

Potting and repotting

It may be desirable to repot a plant to place it in a more decorative container, because it is nearly root-bound, or to change the medium it is growing in. Actively growing house plants normally require only occasional repotting. Slowly growing plants only rarely require repotting, while plants that grow more quickly require more frequent repotting. Foliage plants require repotting when their roots have filled the pot and are growing out of the bottom but before they start circling the inside of the pot.

Repot a plant as soon as it becomes necessary. The pot selected for repotting should be the next-larger diameter available; for larger plants it should have a diameter no more than about 2 inches larger than the pot in which the plant is currently growing. It should also be clean and provide drainage as discussed above. Wash soluble salts from clay pots with water and a scrub brush. Wash all pots in a solution of 1 part liquid bleach to 9 parts water in order to reduce the incidence of soilborne disease. Allow containers to soak in the bleach solution for at least 10 minutes.

Before potting or repotting, the medium should be thoroughly moistened. Most plants can be removed easily from their pots if the lip of the container is knocked upside down against any solid object. Hold your hand over the soil, straddling the plant between the fore and middle fingers while knocking it out of its container. If the plant has become root-bound, cut any roots that encircle the plant so that the roots will develop. If the soil surface has accumulated salts, remove them. Set the root ball in the middle of the new container and fill soil under the root ball and around the sides between the root ball and pot. Do not add soil above the original level on the root ball unless the roots are exposed or some of the surface soil has been removed. Do not pack the soil. To firm or settle it, tap the pot on a tabletop or gently press the soil with your fingers.

If drainage holes are too large and the potting soil comes out of the holes, place a few shards of discarded ceramic or clay pots over drainage holes to prevent soil loss. Do not place any material other than the potting mix in the container. Contrary to popular belief, placing gravel or other coarse-textured material in the bottom of the pot does not improve drainage due to the fundamental physical properties of porous media. In fact, it will usually impede drainage and increase the saturated zone of soil in the container, which can result in root disease. Water moves through soil by the forces of gravity and capillarity. Very small, capillary-sized pores predominate in most field and potting soil and result in water being pulled downward through the pore spaces of the soil column to the bottom of the pot. Capillary forces govern water movement unless soil is saturated, in which case water moves downward by gravitational force. Layers of gravel, clay pot shards, or similar coarse materials contain few if any small capillary pores. If a layer of such a coarse material is present in the bottom of a pot (or anywhere within a soil column or con-

tainer), the downward movement of water (i.e., drainage) will stop when the water front encounters the coarse layer since there are no capillary pores to continue pulling the water down. Thus, capillarity cannot pull the water out of the pot and the soil just above the interface of the two materials becomes saturated before water resumes downward movement in and through the coarse layer by gravitational force.

If improved drainage is desired for a potted plant, two things can be done. One is to increase the porosity of the soil media by incorporating additional perlite or similar bulking material. The second is to place the plant in a deeper container, which will increase the volume of soil media that remains well drained and unsaturated since it is the soil layer at the bottom of the container that remains saturated for a period after watering.

Thoroughly water the plant and container to wet and settle the new potting media. After watering and settling, the soil level should be sufficiently below the level of the pot to leave headroom for watering. A guideline is to leave about 1 inch of headroom in a 6-inch diameter pot and proportionately more or less for other pot sizes. A properly potted plant has enough headroom to allow water to drain through the soil and thoroughly moisten it.

Training and Grooming

Training and grooming refer to a number of activities, including pinching, pruning, and disbudding. Pinching is the removal of 1 inch or less of new stem and leaf growth just above the leaf node. This leaves the plant compact and stimulates new growth. It can be a one-time or continual activity, depending on the plant's requirements and the appearance desired by the plant owner. Frequent pinching will make a plant compact but well filled out. Pinch growing tips of the tallest stems, removing them close to a node. New growth that forms just below the pinched tip makes the plant bushy. Pruning removes entire branches or shoots and is done sometimes for the sake of appearance, to improve a plant's structure, or to remove dead plant material. Disbudding is a related care activity in which certain flower buds are removed either to obtain larger blooms from a few choice buds or to prevent flowering in a very young plant or recently rooted cutting that should not bear the physical drain of flowering.

Keeping house plants clean and neat not only improves their appearance but also reduces the incidence of insects and disease problems. Remove all spent flowers, dying leaves, and dead branches. Keep leaves dust-free by washing them with plain lukewarm water; a mild soap may be added to the water if needed to remove dust from the foliage (cover the pot to prevent soap from entering the soil). If the tips of leaves become brown and dry, trim and shape them neatly with sharp scissors.

Care of Potted Flowering and Holiday Plants

When potted flowering holiday plants are brought into a home where the light and relative humidity are low and the temperatures are maintained for human comfort, many of these plants do not perform well. Do not expect to hold over a holiday plant from year to year. Enjoy them while they are attractive and in season then discard them, or plant them outdoors if conditions permit.

Mums (Chrysanthemums)

A potted blooming mum (fig. 10.1) makes a nice accent in the home. It should have a life of 4 to 6 weeks or more indoors if given proper care. Provide mums with several hours each day of bright, indirect sunlight near a window to keep plants growing without fading bloom prematurely. Plants can be displayed in another part of the

Figure 10.1

Chrysanthemum.

home for short periods of time. Water when the soil becomes dry to the touch and the pot becomes noticeably lighter in weight. If temperatures are warm, daily watering may be needed. Do not let the potting mix become completely dry; be sure the plant does not stand in water after watering. Fertilizer will not be needed. Remove dead leaves and faded blooms as they develop to keep plants in good appearance. Plants will not reflower in the home, but after flowering they can be planted in the garden, where they often flower again in the fall and sometimes in the late spring. After planting in the garden, trim plants once or twice to keep them from getting leggy and trim them after each flowering cycle.

Poinsettia

Poinsettias (fig. 10.2) require bright light and should be kept away from drafts. A temperature between 65° and 70°F is ideal. Avoid temperatures below 60°F and above 75°F. Keep plants well watered but do not overwater. Some of the newer, long-lasting varieties can be kept attractive all winter.

Figure 10.2

Poinsettia.

Gardeners frequently ask whether they can carry their poinsettias over to bloom again next year. Satisfactory results can be obtained in mild climate zones of the state, where poinsettias can be planted outdoors. It is questionable whether the results are worth the effort in colder areas, as the quality of home-grown potted plants seldom equals that of commercially grown plants. For those who wish to try, the procedures outlined below can be followed.

After the bracts fade or fall, set poinsettia plants outdoors or place containers where they will receive indirect light and temperatures of 55° to 85°F. Water sparingly during this time, just enough to keep the stems from shriveling. Cut the plants back to within about 5 inches from the ground and repot in fresh soil. As soon as new growth begins, place in a well-lighted window. After danger of frost is over, place pots outdoors in a partially shaded spot. Pinch the new growth back to get a plant with several stems. Do not pinch after September 1. About Labor Day, or as soon as the nights are cool, bring plants indoors. Continue to grow them in a sunny room with a night temperature of about 65°F.

Poinsettias bloom only during short days. To initiate blooms, exclude artificial light, either by covering with a light-proof box each evening or placing in an unlighted room or closet, for a minimum of 12 hours of darkness. Once short-day treatment is started, it must continue every night until plants develop the red color. Plants require full light in the daytime, so be sure to return them to a sunny window. Start the short-day treatment about mid-September to have blooms between December 1 and Christmas.

Figure 10.3

Azalea.

Figure 10.5

Amaryllis.

Azaleas

Azaleas (fig. 10.3) require bright sunlight and constantly moist but not saturated soil to remain healthy. Flowers can last up to 6 weeks in the home. A night temperature of 60°F prolongs bloom. Azaleas drop leaves readily if kept in low light. Use a fertilizer formulated especially for azaleas and, when repotting, use a mixture high in sphagnum moss. Azaleas can be planted in a shady spot in the garden during the summer months. Examine them frequently and keep them watered during dry periods. Greenhouse azaleas are not hardy and must be brought indoors if long-term freezing weather is expected.

Gardenias

Gardenias (fig. 10.4) grown indoors need special care. They require acidic soil and should receive the same nutritional care as azaleas. The night temperature should be near 60°F, and the humidity around the plant should be kept high. High temperatures or low light intensity result in flower bud drop.

Amaryllis

The secret of growing amaryllis (fig. 10.5) is to keep the plants actively growing after they finish blooming. Keep the plants in full sun, with a night temperature above 60°F. As soon as the danger of frost has passed, set the plants in the garden in a semishaded spot. In the fall, before the danger of frost, bring them in and store them in a cold, dark place to rest. They will be ready to force again about January 1. Bring them into a warm, lighted room and water moderately to begin new growth.

Christmas Cactus

At least three related species of Christmas cactus (fig. 10.6) are sold, in addition to a number of cultivars. All have similar cultural requirements. The secret of good bloom is to control the temperature and photoperiod. Plants initiate and develop buds and bloom if given bright light, short days, and night temperatures from 55° to 65°F. Flower buds will fail to develop if the

Figure 10.4

Gardenia.

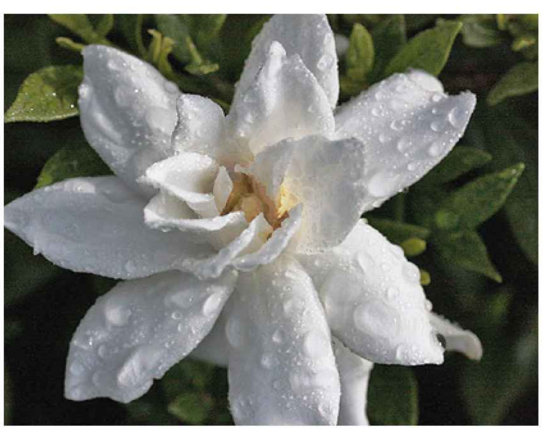

Figure 10.6

Christmas cactus.

nighttime temperature regularly reaches 70°F. For Christmas bloom, the light and temperature treatment should be started in mid-September and continue for about 8 weeks. Christmas cacti bloom best when somewhat root-bound. Repotting is necessary only about once every 3 years. These plants grow naturally shaded by a canopy of leaves. Full sunlight is beneficial in midwinter, but bright sun during summer months can make plants look pale and yellow. Christmas cacti require less water from October to March than they do from April to September, when growth is active. Care should be taken that soil never becomes waterlogged during the dark days of winter.

Cyclamen

Cyclamens (fig. 10.7) require full sunlight and cool temperatures, with a night temperature from 50° to 60°F. They must be watered whenever the surface of the soil is dry. Flower buds will fail to develop if night temperature exceeds 75°F or if light intensity is low. High light intensity and cool (70°F or lower) temperatures increase flower longevity. Cyclamens can be carried over, but, as with poinsettias, home-grown plants are seldom equal to those grown by a commercial grower. Let the plants die down after they finish flowering. Repot the fleshy corm in June, with the top of the corm above the soil line. Allow resting bulbs to dry, but do not allow them to become shriveled.

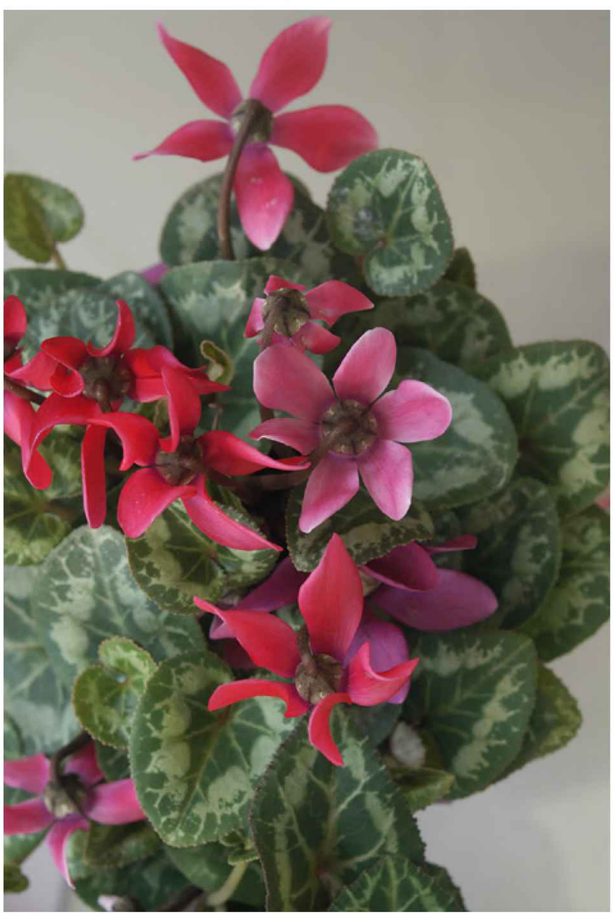

Figure 10.7

Cyclamen.

Common House Plant Problems

Problems with house plants typically arise from improper care (too much or too little water and fertilizer), root diseases, poor sanitation, adverse environmental conditions (low light intensity, low relative humidity), and insect or mite pests. Routinely check your house plants and treat problems promptly. When dusting and grooming plants, examine them for signs and symptoms of pest infestation or other types of damage and problems. A quick guide for diagnosing house plant problems is found in table 10.2. In many instances, solving the problem or treating the pest is difficult, and often it is unlikely that a severely damaged plant can be returned to a desirable level of performance. Once the problem has been diagnosed, it is sometimes not practical or effective to restore the plant, solve the problem, or manage the pest, and it is better to discard the plant and purchase a new one.

Environmental Problems and Improper Care

The majority of house plant problems are caused by improper care and by environmental factors in the home that are unfavorable to optimal plant growth. Understand the growing requirements of each of your house plants (see table 10.1). The majority of problem symptoms can be caused by a number of factors:

- Brown leaf tips and burned leaf margins are usually caused by

Table 10.2.

GUIDE FOR DIAGNOSING HOUSE PLANT PROBLEMS

Symptom	Possible causes
brown or scorched leaf tips	poor health from overwatering, excessive soil dryness (especially between waterings), excessive fertilizer or other soluble salts in the soil
	specific nutrient toxicities (e.g., fluoride, copper, or boron)
	low humidity
	pesticide or mechanical injury
leaf spots, blotches, blemishes, blisters, or scabby spots	intense light (sunburn) associated with a recent move of the plant
	chilling injury (below 50°F)
	chemical spray injury
	overwatering
	fungal or bacterial infections (rare unless plants have recently come from outdoors or greenhouses)
foliage yellow-green on older leaves	insufficient fertilizer, especially nitrogen
	poor root health from pot-bound growth, compacted soil, poor drainage, overwatering
	insufficient light
foliage yellow-green on newer leaves	overwatering, soil pH imbalance
	micronutrient deficiency
foliage yellow-green generally throughout plant	too much light, overwatering, underwatering
	insufficient fertilization
	high temperatures, especially when associated with dryness
	insect infestation
leaf drop; sudden wilting of foliage	poor root health from overwatering, excessive dryness, excessive fertilizer, or other soluble salts in the soil
	compacted soil or pot-bound roots
	sudden change in light, temperature, or relative humidity
	toxic chemical poured into soil
roots brown, soft or rotted; roots with tissue that can easily be slipped off, leaving behind the stringlike center tissues, associated with one or more of the symptoms noted above	poor root health from overwatering, excessive dryness, excessive fertilizer, or other soluble salts in the soil
	compacted soil or poorly drained container
yellowed leaves with tiny speckling; leaves later bronzed and drying; webbing may be noted near growing points	spider mite infestation
leaves covered with a sticky substance; mold growing on leaves; small brown, white, or greenish objects seen on leaves or in crotches of branches; leaf drop or branch dieback; leaf or growing point distortion	scale, mealybug, or aphid infestation

Source: Adapted from Powell and Lindquist 1983, p. 5.

Figure 10.8

Use soapy or plain water spray to control insect and mite pests.

overfertilization (salt buildup) or excessively dry soil, but they may also result from too much sun or heat through a window, low relative humidity, or a drafty setting.

- Weak growth or light green to yellow leaves may be due to underfertilization (lack of nitrogen), root rot, exposure to too much or too little light, or sucking insects and mites.
- Small leaves with excessively long internodes (leggy growth) are usually caused by unfavorably low light levels.
- Yellowing and dropping leaves can be caused by low light intensity, chilling, overwatering, poor soil drainage, or soilborne insect or disease pests.
- Wilting is usually caused by underwatering or overwatering or light that is too intense, but it may also be due to root decay from soil pathogens. Inspect root systems whenever wilting occurs.
- A lack of flowers on a house plant that normally flowers may indicate that night temperatures are too high or that the duration or intensity of light is unfavorable.
- Soft stem bases usually are an indication of overwatering. Soggy soil can result from overwatering or improper drainage.

Controlling Insect Pests and Mites

Keeping your house plants clean and inspecting them regularly are the best defenses against insect pests and mites. The most common house plant insect and mite pests are aphids, fungus gnats, spider mites, mealybugs, scales, whiteflies, and thrips. The strategies against these pests depend on the pest and the plant. Consult the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden, for the current chemical control options for insect and mite pests on house plants. In some instances, control of the pest is impractical or nearly impossible once the pest is established. The best course of action in these situations is to discard the plant and obtain a new one.

Whenever you detect insect or mite pests on an established plant in your home or office, isolate the plant immediately to prevent pests from spreading to other plants. As an additional precaution, wash your hands after touching insect- or mite-infested plants.

Some soft-bodied insects and mites can be removed by forcefully washing the plant leaves and stems with plain water (fig. 10.8). Others may require insecticidal soap or chemical controls, available as sprays or soil drenches. If a chemical control is chosen, use an insecticide or miticide that is recommended and labeled for use on house plants and follow all the label directions and safety precautions. If you use a formulation specifically for house plants, be certain that it is recommended for use on your particular plant. When applying sprays, wear protective gloves and spray stems, leaves, and leaf undersides thoroughly. Spray outdoors so that the spray residue will be dispersed outside and you will not have to worry about damaging furniture surfaces. Soil drenches can exterminate soilborne insects; the potting medium should be watered well before application.

Aphids

Aphids are small insects found on new growth or on the underside of leaves. They suck plant juices and excrete a shiny, sticky sap, or honeydew, that attracts ants and sooty mold growth. Aphid infestations are often evident by the white cast skins that are shed and left behind when aphids molt. Aphids can attack almost all house plants, causing leaves to curl and become distorted.

Fungus gnats

Fungus gnats become a nuisance indoors when the adult mosquito-like flies emerge from potted plants or flower boxes. These flies are harmless to humans. Adult fungus gnats are dark, delicate-looking insects, similar in appearance to mosquitoes. They are relatively weak fliers, but the adults can be a nuisance indoors. They generally remain near potted plants and often run or rest on growing media, foliage, or litter. Adults are attracted to lights and may be noticed for the first time near windows.

Adult fungus gnats are about $\frac{1}{10}$ to $\frac{1}{8}$ inch long, grayish to black, slender, and mosquito-like, with long, delicate legs and one pair of clear wings. Fungus gnats infest moist organic soil and container media, where their larvae feed on organic matter and roots. Females lay tiny eggs in moist organic debris or potting soil. Larvae have a shiny black head and an elongate, whitish to clear, legless body. The life cycle takes about a month, and reproduction can be continuous in the warmth of most homes. Adults live about 7 to 10 days.

Larvae of these flies feed on roots, and if populations are very high, they can stunt plant growth in African violets, carnations, cyclamens, geraniums, poinsettias, and foliage plants. Symptoms of infestation include sudden wilting, loss of vigor, poor growth, off-colored plants, and foliage loss. In addition to larvae chewing on roots, both larvae and adults can spread plant pathogens and may promote disease.

Management of fungus gnats centers on cultural control. Inspect plants carefully for signs of insect infestation before purchasing them, and inspect house plants that you have left outdoors during warm weather before bringing them back into the house. To prevent fungus gnat infestations in house plants, always use sterile potting soil. Overwatering and poor drainage may result in fungus gnat buildup. Eliminate freestanding water and allow soil to dry as much as possible between irrigations. Practice good sanitation by removing old plant material and debris in and around pots. Although insecticides are available to kill adults and larvae, these products are rarely warranted to control these flies around homes.

Figure 10.9

Obscure mealybugs. *Photo:* J.K. Clark

Mealybugs

Mealybugs are small, oval, stationary insects that cover house plants with a cottony, powdery material along the veins of leaves or where the leafstalk joins stems (fig. 10.9). Typical symptoms are stunted plant growth and leaf wilting. Mealybugs, like aphids, excrete honeydew and can be controlled using similar strategies. Mealybugs are common pests of palms and succulents and may infest plant roots.

Figure 10.10

Spider mites and webbing. *Photo:* J.K. Clark

Mites

Several mite species can attack indoor plants, often causing severe injury. The most common mite is the twospotted spider mite. Spider mites have a wide host range, and very few indoor plants are immune to attack. Adult spider mites are about 0.5 mil long and are usually found on the underside of leaves. A 10× hand lens is useful in identifying these pests.

Figure 10.11

Brown soft scale. *Photo:* J.K. Clark

Feeding injury on many plant species usually involves lighter-colored, stippled areas of leaves. Webbing is also produced (fig. 10.10). Severe spider mite infestations cause leaves to dry and fall from the plants. At 75°F, mites develop from egg to adult in about 2 weeks.

Other mites, including the broad mite and cyclamen mite, can cause problems, too. These mites are very small (0.2 mm long) and almost impossible to see without a hand lens. Infestations are recognized by plant injury symptoms rather than by seeing the mites. Most feeding injury occurs on young foliage. Injury on these new leaves is characterized by thickened and brittle foliage, with leaf margins cupped downward and stunted. Many of these symptoms are characteristic of injury by chemicals, so infestations can go unnoticed for long periods of time.

Scales

Scales are small, brown or grayish, stationary insects that have a shell-like covering (fig. 10.11). A common pest of many house plants, they suck plant juices and excrete honeydew, initially giving leaves a shiny, sticky surface but later stunting plant growth and discoloring leaves. They sometimes are difficult to detect on fern fronds because they resemble spores. Scrape scales off plants, wash the plants with soapy water. Scales may infest plant roots, which can become a source of chronic infestations of stems and leaves. In these cases, it may be necessary to repot the plant, removing much of the soil around the roots and drenching the soil.

Thrips

Thrips are small, slender, dark-colored insect pests less than ⅛ inch long that feed on plant leaves and flowers, distorting both. They are typically found on the underside of leaves and often leave shiny black dots of fecal excrement. Leaves often turn yellow and drop, but heavy infestations result in leaves that have silvery gray

areas. To control thrips, wash plants with a forceful stream of water and spray with insecticide. Remove flowers of infested plants because thrips often infest them.

Whiteflies

Both adult and juvenile whiteflies attack house plants. The juveniles attach to the underside of leaves, suck plant juices, and excrete honeydew. The adults can be seen flying about the plants. Whiteflies infest poinsettias and many other plants, causing leaves to yellow and drop.

Controlling House Plant Diseases

If a purchased plant is disease-free, infectious disease will rarely be an important role in the indoor life of the plant. The many foliar leaf spots and blights that can occur on plants outdoors or in the production greenhouse will not usually be a problem in the home or office because of the lack of damp air and splashing water. Of course, disease symptoms such as discolored stems and roots or leaf spots that are present on plants when they are purchased will not disappear. These plants should be rejected.

Recognizing infectious diseases on flower, leaf, and stem parts of plants is sometimes more difficult than recognizing insect or mite pests because the pathogens cannot be viewed directly. Most often, the pathogens will be fungi. A fungus grows on a leaf similar to the way mold grows on bread or a rotted spot grows on a fruit or vegetable. Circular lesions of growth sometimes overlap one another, giving a blotchy appearance. Concentric rings in the lesion give a bullseye appearance. Spores of these fungal pathogens appear on the surface of plant leaves as fluffy, moldy growth like that seen in powdery mildews. Look for black, pinpoint-like pustules within the lesion. These pustules are actually fungal formations in which many spores are produced and pushed to the outside. Many different fungal pathogens can be found on foliage plants, and they produce different sizes, shapes, and colors of lesions.

Bacterial diseases sometimes appear as oily, greasy, or water-soaked spots on leaves. These are often visible by viewing the lesion from the underside of the leaf. Some bacterial diseases are systemic in nature and cause wilting and general yellowing of plants. Systemic diseases may occasionally cause rotting or cankering of the stem tissue. These cankers or rots will be soft and mushy in appearance and may have an unpleasant odor.

Infectious root rots can be diagnosed to some extent by direct observation of the root system. Off-color or brownish to blackish roots, especially if rotted at the root tips, often indicate that root rot is present. Healthy roots should be entirely white or white under their outer covering. A common misconception is that being able to pull off outer root tissue with your fingers (leaving the string-like center of the root behind) is a good sign that root rot is present. This is not a reliable symptom of root rot, however.

Consult the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden, for the current chemical control options that are available for diseases of house plants.

Systemic bacterial diseases

Many bacterial pathogens found on indoor plants can invade the vascular tissues of the plant and spread throughout its system. If conditions are favorable, these pathogens may begin to multiply in certain areas of the infected plants and cause stem rots, leaf blights, wilts, and even root rots. They are spread by splashing water and contaminated hands and pruning tools.

Commonly encountered systemic bacterial diseases include soft stem rot of *Aglaonema*, *Dracaena*, *Kalanchoe*, and *Syngonium* spp. plants (caused by *Erwinia carotovora*); and bacterial stem rot, leaf spot, and wilt of *Aglaonema*, *Dieffenbachia*, *Philodendron*, and *Syngonium* spp. plants (caused by *E. chrysanthemi*).

Control tactics for these diseases depend on recognizing the systemic nature of the pathogen. Chemical sprays

are not effective because the pathogens are throughout the plant and deep within its tissues. The organisms are most active under warm, damp conditions on soft tissues in heavily fertilized plants. Common systemic bacterial diseases can be managed reasonably in many cases in the interior environment through a combination of sparse watering and low fertilization. The relatively cool temperatures of many households are often the reason that the bacteria usually do not proliferate and cause a yellowing and wilting of the affected plant. Splashing water must be avoided when trying to control bacterial diseases.

Localized bacterial diseases

Species of *Pseudomonas* and *Xanthomonas* bacteria cause leaf spots or leaf blights on many plants growing indoors. Common hosts of xanthomonads are *Dieffenbachia* spp., *Philodendron scandens* ssp. *oxycardium*, English ivy, and *Pileas* and *Pellionia* spp. Pseudomonads are found on *Aglaonema*, *Dracaena*, and *Monstera* spp., as well as on pothos. The diseases are characterized by dark green, water-soaked spots that may turn tan, dark brown, or black with a yellow border. The spots can enlarge until the entire leaf blade is involved. Sometimes these lesions spread into the petioles and stems and may look almost exactly like the systemic bacterial diseases previously mentioned. Control of these diseases generally involves prompt removal of infested plant parts. Clean hands with soap and water and disinfect pruning tools in 70% alcohol after such removal actions.

Powdery mildews

Fungi that cause powdery mildew are host specific. They are seen often on grape ivy, kalanchoe, begonias, or pileas. The white growth appearing on leaves, flowers, or stems is the fungus growing on the surface of the tissue. Powdery mildew usually will not kill a plant. The unsightly fungus lesions and partial defoliation that occur greatly reduce the quality of the plant, however. Fortunately, environmental control of powdery mildew can be successful. Reduce the high humidity that often occurs at night by watering early in the day. Use fans to circulate the air, but avoid drafts such as those caused by cold windows or doors.

Water mold root rots

Pythium and *Phytophthora* spp. fungi are often said to cause water molds because they have a spore stage that is adapted to spread by swimming in water. These organisms attack a wide variety of plants, causing root rots, stem rots, and cutting rots. Many times, *Pythium* spp. will not kill a plant. These organisms will “prune” the root system, resulting in poor growth, yellowing, or stunting of the top portion of the plant. Infectious root rot can cause serious health problems indoors, especially when overwatering occurs. Of course, overwatering can occur as media ages, settles, and packs in the bottom of containers. An initially good root environment may become inhospitable as time progresses. Preventing infectious root rot involves providing good soil aeration, drainage, and watering frequency of the plant. Root rot often may follow an episode of high salt levels. If soluble salt levels are maintained at low rates, root rot can be avoided.

Fungal leaf spots and blights

Fungi that cause leaf spots and blights are generally spread when water containing spores lands on plants. Most notable among these fungi are *Cercospora*, *Colletotrichum*, *Curvularia*, *Fusarium*, *Coniothyrium*, *Helminthosporium*, *Leptosphaeria*, and *Alternaria* spp. *Botrytis* spp., which have a wide host range, produce spores and infect only if the relative humidity is high for several hours at a time. Many leaf-spotting fungi require water on leaf surfaces for several hours for infection to occur. Avoid splashing water and water early in the day so plants can dry as quickly as possible. The best control is to remove and discard infected leaves.

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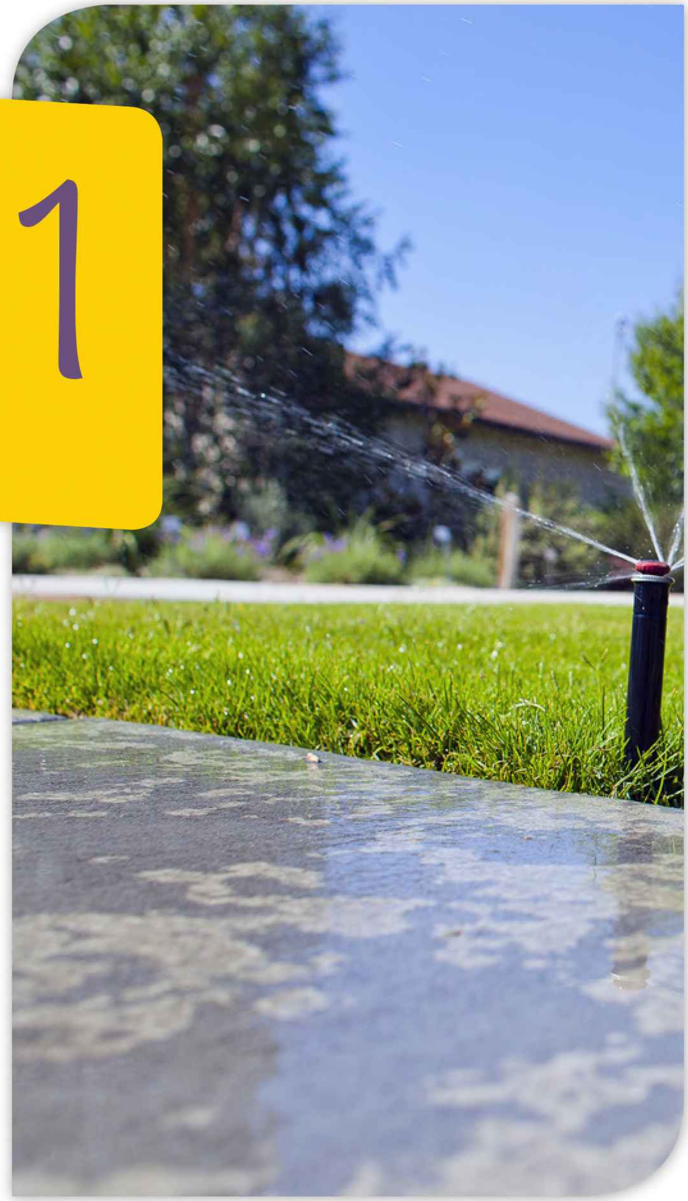
Lawns 11

M. Ali Harivandi



Learning Objectives

Understand the basic functions of turfgrass in California landscapes.

Understand the procedures involved in lawn establishment and maintenance practices for commonly used lawn grasses in California.

Learn the basic steps in renovating an old lawn.

Become acquainted with the names and important characteristics of the recommended cool-season and warm-season turfgrasses for California lawns.

Learn how to be an informed consumer when purchasing seed, stolons, and sod.

Learn the basic concepts of routine and sustainable turfgrass maintenance and management practices (mowing, grasscycling, fertilization, irrigation, dethatching, aeration, and weed, disease, and insect management).

Lawns

A turfgrass lawn is no longer a simple or obvious choice in California. The days of plentiful water and relatively unrestricted use of pesticides are gone forever. Today, establishment and maintenance of turfgrass lawns can be regulated by local restrictions. At worst, homeowners may be cited for excesses in water or pesticide use or for water or pesticide runoff into the gutter; at best, home gardeners are constantly reminded by utility bills, the media, and neighbors that lawn maintenance consumes community resources (e.g., water) and runoff from lawns may pollute the environment.

Is turfgrass, therefore, a vanishing component of California landscapes? The answer is no, for two good reasons: people truly enjoy turfgrass lawns, and no other material, either natural or fabricated, functions as effectively as a playing surface for recreational activities and team sports or as a landscape surface for parks and cemeteries. Recent environmental concerns about water shortages, fertilizer runoff, and pesticide residues have focused attention on better planning and more efficient maintenance of lawns and on planting turf species that use less water. The management program must meet the home gardener's desire for a beautiful lawn, and at the same time, it must be environmentally acceptable and sustainable. Without a sound management program, a high-quality lawn can deteriorate over a period of years.

Although the following discussion highlights some of the important aspects of lawn establishment and maintenance, not all aspects of lawn management are covered in detail. Table 11.1 provides a summary of establishment and maintenance practices for commonly used lawn grasses. UC publications and websites listed at the conclusion of this chapter, especially the *UC Guide to Healthy Lawns*, contain more detailed information on specific topics.

Establishing a Lawn

A lawn may be established from seed or it may be established vegetatively from plugs, stolons, or sod. The method chosen depends on the species of grass desired, the environmental situation, time limitations, and financial considerations (see the section "Seed versus Sod," below). The same fertilizer requirements and seedbed preparation apply for both seeding and vegetative establishment. Once a new lawn is established and growing well, a comprehensive maintenance program will keep it healthy and attractive.

Preplant Weed Control

Before planting, check the area to be planted for weeds. Grassy (monocot) weeds such as velvetgrass and dallisgrass are particularly troublesome in lawns; perennial grasses sometimes used for turf, such as bermudagrass, are weeds in lawns of other species and should be eliminated before planting. Almost all weeds can be eliminated with a preplant application of glyphosate, a nonselective herbicide. Hard-to-kill weeds, such as bermudagrass, may require several applications. Apply glyphosate when weeds are actively growing (irrigate

and fertilize if needed to encourage weeds to grow vigorously prior to each herbicide application). Repeat applications may be necessary. If you suspect the presence of annual weed seeds, water the site before lawn seeding or sodding to allow weed seeds to germinate. Then shallowly cultivate the soil to eliminate the seedlings.

Preplant Installation of Irrigation and Drainage

Install the irrigation system and drainage system (if necessary) before final grading. If considerable subsoil grading is necessary, stockpile topsoil for use in final grading.

Soil Preparation

Rototill the soil as deeply as possible and remove construction debris and other trash from the planned lawn area before grading. If these materials are buried before planting, they may cause mowing hazards, restrict root growth, and impede water movement. When grading, slope the soil away from buildings and allow the lawn area to settle for 1 to 2 weeks before seeding or sodding. Several wetting and drying cycles will aid settling and help locate low spots that need filling. The minimum topsoil depth should be 6 to 8 inches. Avoid planting lawns on steep slopes or berms to reduce water waste from runoff. It is also dangerous to mow lawns on steep slopes and difficult to irrigate and fertilize effectively. Generally, a slope of 1 to 2% away from buildings is optimal.

Fertilization

Apply a starter fertilizer containing the three major nutrients (nitrogen, phosphorus, and potassium) before turf establishment and incorporate it to a depth of 2 to 3 inches. Table 11.2 gives

Table 11.1.

COMMON CALIFORNIA LAWN GRASSES AND THEIR MAINTENANCE

Grass		Establishment				Maintenance	
Common name	**Scientific name**	**Time**	**Rate, seed or stolons, per 1,000 sq ft**	**Mowing height (in)**	**Fertilizing, weight N per year***	**Root depth, water frequency†**	**Vertical mowing‡**
Warm-season							
common bermudagrass	*Cynodon dactylon*	late spring or early summer	1 lb seed	1.0	spring-summer-fall, 2–4 lb	60 in, infrequent	yes
hybrid bermudagrass	*Cynodon* spp.	late spring or early summer	4–6 bu stolons or sod	0.50–0.75	spring-summer-fall, 4–6 lb	60 in, infrequent	yes
St. Augustinegrass	*Stenotaphrum secundatum*	late spring or early summer	3–5 bu stolons or sod	0.5–1.5	spring-summer-fall, 4 lb	12–24 in, moderate	no
zoysiagrass	*Zoysia* spp.	late spring or early summer	4–6 bu stolons or sod	0.5–1.0	spring-summer-fall, 2–4 lb	60 in, infrequent	yes
Cool-season							
Kentucky bluegrass	*Poa pratensis*	fall or spring	2–3 lb seed or sod	1.5–2.0	fall-spring, 4–6 lb	6–12 in, frequent	yes
perennial ryegrass	*Lolium perenne*	fall or spring	6–9 lb seed	1.5–2.0	fall-spring, 4 lb	6–12 in, frequent	no
tall fescue	*Festuca arundinacea*	fall or spring	8–10 lb seed or sod	1.5–3.0	fall-spring, 4 lb	18–30 in, frequent	no

Source: Adapted from an original prepared by Victor A. Gibeault, UC Cooperative Extension Environmental Horticulturist, UC Riverside, and John Van Dam, Turf Advisor, UC Cooperative Extension San Bernardino County.

Notes:

*Suggested application seasons; amount given is total lbs actual N per 1,000 sq ft per year. Apply only 1 lb N per application.

†Frequent = irrigation every 1 to 3 days during summer; infrequent = irrigation every 7 days, approximately. See chapter 4, "Water Management," for more detailed information on irrigating turfgrass.

‡Indicates need for periodic thatch removal.

examples of appropriate fertilizers and application rates.

Seed versus Sod

Seeding a lawn is generally less expensive than sodding. Establishment is more difficult with seed, however, and if reseeding certain areas or even an entire lawn is necessary due to the initial seeding failure, the overall expense incurred may exceed that of sodding. In addition, during the time required for seed to germinate and to become rooted well, the area is vulnerable to erosion and sedimentation. Sodding also provides an immediately pleasing, quickly functional turf that can compete with viable weed seeds already in the soil. When using seed, a more intensive weed control program may be required during the establishment period.

Seeding

A well-prepared seedbed is essential for the establishment of grasses. Till the seedbed to a depth of 6 to 8 inches, with the starter fertilizer worked into the top 2 to 3 inches of soil before seeding. Prepare a smooth, firm seedbed of loose soil, then divide the seed in half and sow it in two directions perpendicular to each other. Cover the seed to a depth of 1⁄16 to 1⁄8 inch by raking it in and lightly rolling or firming the soil. Avoid creating a smooth surface. The finished seedbed should have shallow uniform depressions (open rows) about ½ inch deep and 1 to 2 inches apart (e.g., those made by a garden rake or a corrugated roller). Keep the soil moist during the germination period by applying frequent but light irrigations. To prevent puddling or seed wash-off, do not overwater.

Germination of grass seed depends on temperature, moisture, and day-length conditions. Cool-season grasses, such as turf-type tall fescue, Kentucky bluegrass, and perennial ryegrass, are seeded best from mid-September through October. The next-best time would be March through April. Warm-season grasses, such as common bermudagrass, are seeded most successfully from mid-April to mid-May.

Table 11.2.

FERTILIZERS AND APPLICATION RATES

Fertilizer analysis	Application rate (lb/1,000 sq ft)
5-10-5	20
16-20-0	6
10-20-10	10
5-20-10	20
21-0-0	5

Sodding

Soil preparation for sodding is similar to that for seeding, but one must take care not to make deep footprints or wheel tracks before planting. Such depressions restrict root development and give an uneven appearance to the installed sod. A good way to avoid creating those depressions is to work starting from a straightedge on top of a piece of half-inch plywood, moving the plywood sheet across the laid turf. On hot summer days, the soil should be lightly watered just before laying sod to avoid placing the turfgrass roots on a hot, dry surface.

Premium-quality sod is easier to transport and install than inferior grades. Good sod is light, does not tear easily, and quickly extends its root system into the prepared soil. The presence of mildew or a distinct yellowing of leaves is evidence of reduced turf vigor and poor-quality sod. Before ordering or obtaining sod, be prepared to install it quickly, because sod is perishable and should not remain on the pallet or stack longer than 24 hours. Upon delivery, store sod rolls in shade until laid to prevent drying.

To install a sod lawn properly, establish a straight line lengthwise through the lawn area. Then lay the sod on either side of the line with ends staggered, similar to laying bricks. A sharpened masonry trowel is handy for cutting pieces, forcing the sod tight, and leveling small depressions. After the sod is laid, it should be rolled and irrigated immediately, then kept moist by

repeated light irrigation until well rooted.

Sod may be laid any time of the year, but very hot or very cold weather should be avoided. Generally, it is best to lay sod when the turfgrass is actively growing. In California, this period corresponds to late spring and early fall for cool-season grasses. Warm-season turfgrass sod is laid from late April to mid-September.

Stolons and Plugs

Improved hybrid bermudagrasses, zoysiagrass, St. Augustinegrass, buffalograss, and seashore paspalum must be sodded or vegetatively established using plugs or stolons. For plugging or stolonizing, the soil should be prepared as described for seeding. Stolons can be broadcast over an area and covered lightly with soil by disking, or they can be planted in rows in 6- to 12-inch centers. In either case, nodes should be in contact with the soil. Stolons are usually sold by the bushel, with 1 bushel approximately equivalent to 1 square yard of sod. In most parts of the state, the best time to start a hybrid bermudagrass or other warm-season grass lawn from stolons is from late April into summer.

Postplant Irrigation

New seedlings and stolons require frequent but light irrigation to ensure successful establishment. Keep the soil moist, but not wet, for 30 days following planting. During hot periods, three or four light waterings each day may be required. If the soil dries out during germination, seedlings are likely to die. Sodded and plugged areas also require intensive irrigation management. With sod and plugs, however, heavier but less frequent irrigation than is done on a seeded lawn is needed to ensure that the soil beneath the sod or plugs is moist to a depth of 3 inches.

Renovating Old Lawns

A lawn that has a poor appearance but is in fair condition can be renovated. Renovation requires minimal soil preparation and involves less expense and mess than complete replacement. However, if a lawn is badly infested with weeds or if the soil is heavily compacted, has low fertility, or has a very uneven grade, the lawn will require complete replanting. Follow these basic steps in lawn renovation:

Determine the cause of poor quality. Lawns usually require renovation for one or more of the following reasons: ineffective irrigation system, poor irrigation or fertilization practices, inadequate drainage, excessive traffic, improper selection of grass species, weed invasion (which is usually secondary to poor management practices), insect or disease damage, or excessive shade. Correct these problems during and after renovating the lawn.

Remove weeds and undesirable grasses. If possible, plan to control weeds a year ahead of time so they will not compete with the new grass being established. If planning in advance is not possible, apply selective broadleaf weed killers 30 days before verticutting and seeding. If perennial weedy grasses are present, spot-treat with a nonselective herbicide such as glyphosate. Follow label directions closely when using any herbicide.

Closely mow the remaining turf area and remove the clippings. Thorough raking and dethatching after close mowing is recommended to create a loosened surface for seeding or stolonizing.

Dethatch and aerate. Thatch is a buildup of undecomposed organic matter. Because of their high cellulose content, roots and stems are slow to decay and form a semiwaterproof mat between the soil and grass leaves. Thatch should be removed with a mower that has vertical blades, known as a dethatcher or verticutter. After dethatching, lawns growing on heavy or compacted soil should be aerated (see the section “Aeration,” below). In addition to relieving compaction, aeration loosens the soil and makes it suitable for seeding.

Seed, fertilize, and irrigate. Broadcast seed throughout the lawn; broadcast it at a higher rate on bare areas. Starter

fertilizer should be applied at the same time. Top-dress the entire lawn area with a layer about ⅛ inch thick of compost or topsoil. Schedule frequent, light irrigations to keep the soil moist (not wet) until the grass is well established.

- Maintenance. To keep a newly renovated lawn healthy and attractive, begin a comprehensive lawn maintenance program immediately after seedlings are established or when the new grass has been mowed at least twice.

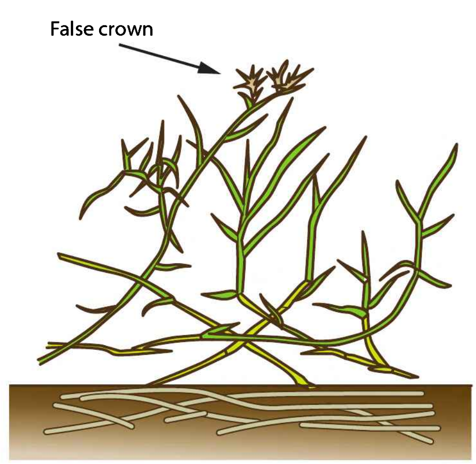
Recommended Turfgrasses for California Lawns

Successful selection of a turfgrass requires knowing how the turf will be used, where it will be grown, what level of quality is desired, and what level of maintenance one can commit to. If very high quality is desired, a great deal of time and effort will be required. The positive and negative characteristics of each species of turfgrass must be evaluated in order to choose the one best suited to a particular situation.

Turfgrasses fall into two basic categories: cool-season and warm-season. Cool-season grasses, such as turf-type tall fescue, Kentucky bluegrass, and perennial ryegrass, have a year-round growing season and provide attractive green winter color. They will turn brown and go dormant in winter in areas where soil temperature drops below freezing. Warm-season grasses, such as bermudagrass, buffalograss, kikuyugrass, paspalum, St. Augustinegrass, and zoysiagrass, go dormant and turn brown in the late fall when soil temperatures drop to about 55°F. They stay brown throughout the winter months and into early spring. Although the brown winter color of warm-season grasses may make them less desirable, their maintenance costs are reduced because they require less water, fewer mowings, and a shorter growing season.

Figure 11.1

Highland bentgrass.



The most commonly grown lawn grasses in California are given in table 11.1. Several other turfgrass species, however, can also be used as lawns, but under specific conditions.

Cool-Season Turfgrasses

Colonial bentgrass *(Agrostis tennuis)* is a cool-season grass that thrives in cool coastal weather. It is adapted to coastal regions in northern California, where it is used for general lawn areas. It does best in cool, humid weather and can tolerate some shade. It may spread very slowly by short rhizomes and also by short stolons, which are often lacking. The thatch layer extends above and below the soil line. It does not form a dense turf.

Creeping bentgrass *(Agrostis palustris)* is a specialty grass used primarily for golf course putting greens, lawn bowling greens, and lawn tennis facilities. The skill and expense needed to maintain this species usually eliminate it as a possible home lawn turf. It is adapted to cool, humid regions and prefers sunny areas but will tolerate some shade. It tolerates low temperatures but will discolor early in the fall.

Highland bentgrass (*Agrostis* spp. c.v. 'Highland') (fig. 11.1) is distinct from Colonial bentgrass but is often classified improperly. It forms solid patches of grass that turn a frosty blue from morning dew during cool seasons. It may form both short rhizomes and stolons.

Chewings fescue *(Festuca rubra* ssp. *commutata)* is a bunchgrass with an upright growth habit. Otherwise, it resembles and behaves similar to its close relative red fescue (see below).

Figure 11.2

Red fescue. (A) The leaves are fine or needlelike. (B) Mature leaves are folded.

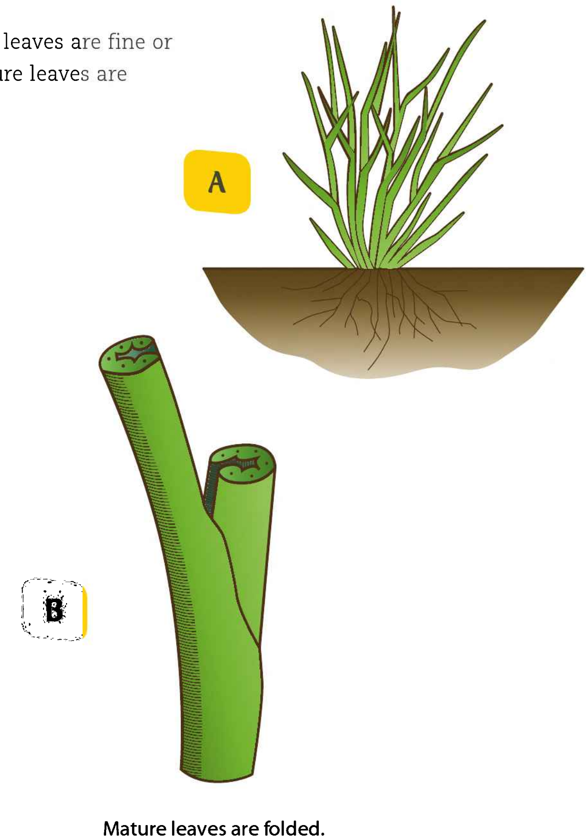
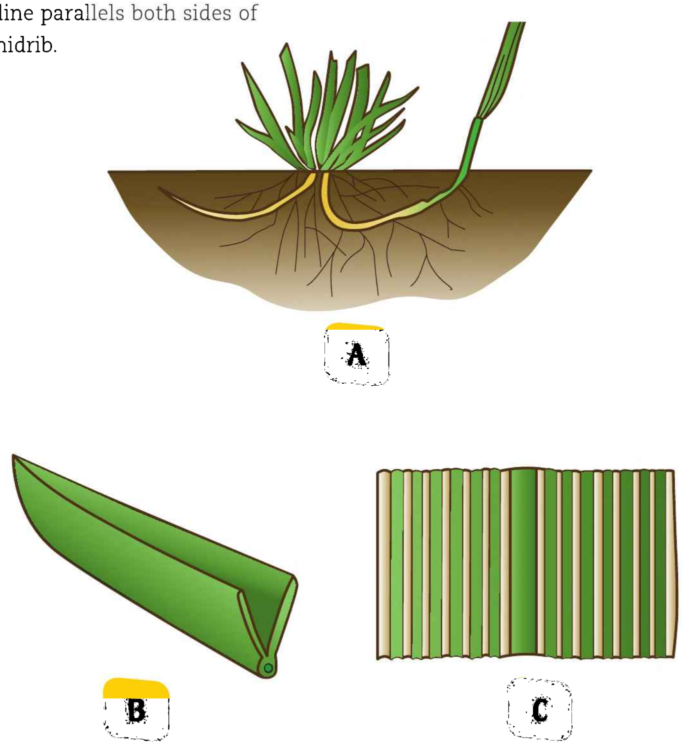


Figure 11.3

Kentucky bluegrass. (A) Strong rhizomes produce a dense turf. (B) The leaf tip is boat shaped. (C) A pale line parallels both sides of the midrib.



Hard fescue *(Festuca longifolia)* is often used in cool-season grass seed mixtures when shade is expected. It grows well on low-fertility soil and in shaded areas and is a good choice for unmowed turf for slopes, median strips, and unused areas of parks. Hard fescue, Chewings fescue, and red fescue (see below) seldom grow taller than 8 inches, except when in flower. At cool, mountain elevations, where they grow wild, they are especially useful for a neglected lawn, such as at a summer cabin, because a single mowing annually removes the seed heads. It does not recover well from severe injury. It is not tolerant of high summer temperatures.

Red fescue *(Festuca rubra* ssp. *rubra)* (fig. 11.2) spreads slowly by very short rhizomes. It is recognized by its fine (narrow) leaf texture. It is often used in cool, shaded mountain sites, such as camps, resorts, and cabins where low inputs of mowing, fertilization, and irrigation are desired. It does not grow well in hot climates, except in shady, dry situations. In areas where Kentucky bluegrass thrives, red fescue forms an excellent companion grass to increase shade tolerance. Red fescue germinates and establishes slowly. It is moderately drought tolerant. This species is also good as an unmowed turf for slopes, median strips, and unused areas of parks.

Kentucky bluegrass *(Poa pratensis)* (fig. 11.3) is a cool-season grass that grows best during the fall, winter, and spring when temperatures are cool. Its growth slows during the warm summer months. Kentucky bluegrass prefers full sun but tolerates some shade. This species is used widely throughout the United States where it is well adapted, but in California it performs poorly in areas with warm to hot summers. When stressed by high temperatures, lack of water, or poor soil, Kentucky bluegrass can be susceptible to disease and weed invasion. For a more disease-resistant turf that offers good color and year-round performance, Kentucky bluegrass is often mixed with perennial ryegrass. Usually two

Figure 11.4

Annual ryegrass.

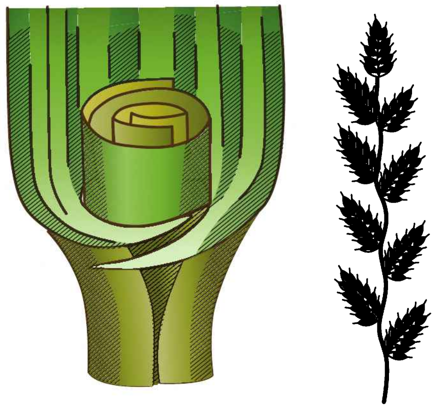
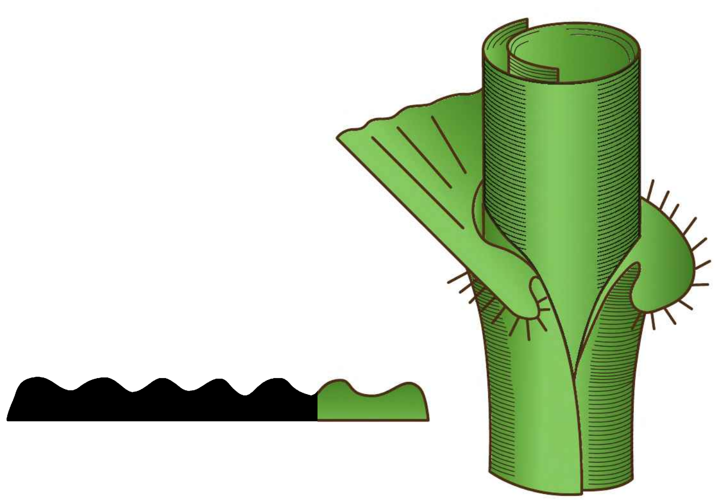


Figure 11.5

Perennial ryegrass.

Figure 11.6

Tall fescue. The top surface of the leaf blade is ribbed; the underside is smooth and shiny.



or more cultivars of each species are used, and at least 15% of the seed mixture should be perennial ryegrass.

Annual ryegrass *(Lolium multiflorum)* (fig. 11.4) is a cool-season grass well adapted to sunny conditions and moderate temperatures. Also known as Italian ryegrass or wintergrass, it is often sown at high rates to overseed warm-season turfgrasses for fall, winter, and early spring color or to provide temporary cover for soil stabilization. It is not otherwise used for turf. Annual ryegrass dies in the late spring to early summer. It often turns yellow and dies before warm-season grasses break dormancy.

Perennial ryegrass *(Lolium perenne)* (fig. 11.5) is a very competitive cool-season grass that is best adapted to coastal regions that have moderate temperatures throughout the year. It prefers full sun but will tolerate partial shade. Perennial ryegrass has the highest wear tolerance of any cool-season grass and can tolerate high traffic. It is often used around homes, schools, and parks. Because it germinates quickly, it is often used for overseeding winter-dormant bermudagrass lawns. Its rapid emergence helps to suppress weeds. It has no rhizomes or stolons, so bare or worn areas should be reseeded. For a turf that better resists traffic and disease, it is often mixed with Kentucky bluegrass.

Tall fescue *(Festuca arundiancea)* (fig. 11.6) is well adapted to sunny or partially shady areas. When densely sown, a pure stand forms a moderate- to coarse-textured lawn that is uniform in appearance with good weed and disease resistance. Tall fescue tolerates warm summer temperatures and stays green during cool, but not severe, winter conditions. New cultivars that are finer in texture and shorter in stature are known as turf-type tall fescue and dwarf turf-type tall fescue. Tall fescue is a good species to plant for general lawn use and is the most common lawn grass in California. It does not spread by rhizomes or stolons, so bare or worn areas should be reseeded.

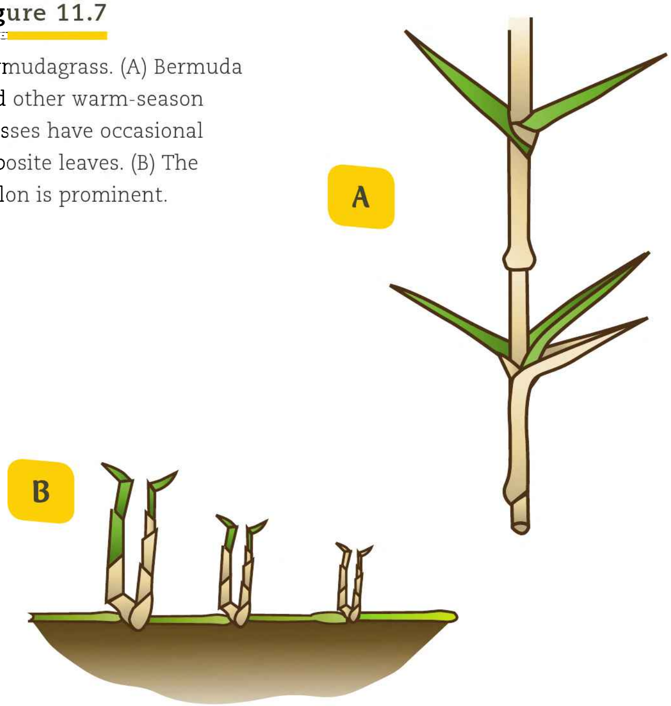


Figure 11.7

Bermudagrass. (A) Bermuda and other warm-season grasses have occasional opposite leaves. (B) The stolon is prominent.

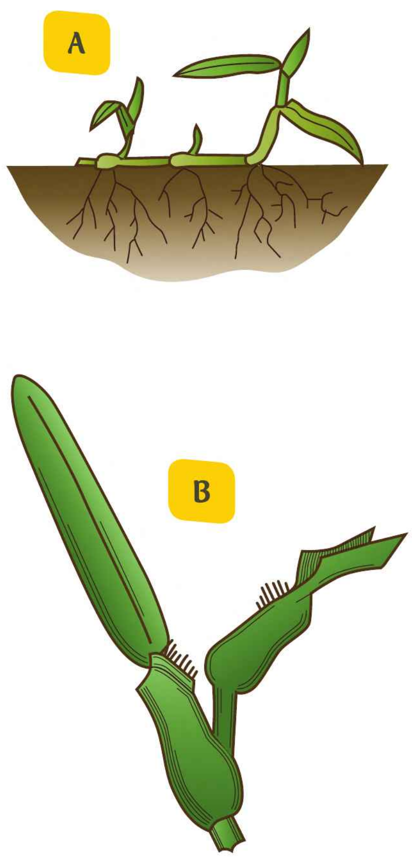


Figure 11.8

St. Augustinegrass. (A) A heavy stolon forms shoots at every node. (B) The collar is narrowed down to form a short stalk or petiole for the leaf blade.

Warm-Season Turfgrasses

Bermudagrass *(Cynodon dactylon)* (fig. 11.7) is well adapted to warm regions of California. It does best in full sun and high temperatures. During periods of extended low temperature, bermudagrass will turn brown. In areas where bermudagrass is well adapted, it is very water efficient and has few pest problems. Seeded and hybrid cultivars are durable and withstand heavy use during the spring, summer, and early autumn months when they are actively growing, but they can be severely damaged from traffic during the winter, when they are dormant and not growing, giving weeds a chance to invade. Bermudagrass can be a troublesome invader of garden areas, since it rapidly spreads by both rhizomes and stolons. The common type also produces viable seed even at very low mowing heights. Hybrid bermudagrasses are propagated only vegetatively (sod or stolons) and require a high level of management. Bermudagrasses are highly drought tolerant but do not tolerate shade.

Buffalograss *(Buchloe dactyloides)* is native to the North American plains. Although it is naturally one of the most drought resistant grasses, its use is currently limited by its long winter dormancy, relatively low turf quality, low shade tolerance, and relatively high cost of seed, plugs, and sod.

Seashore paspalum *(Paspalum vaginatum)* is a very salt tolerant warm-season grass with desirable turfgrass characteristics. This specialty grass is sometimes used in warm-season areas where the soil or irrigation water has a high salt content. It does well near the ocean, where it is subject to saltwater. It is naturally an excellent choice for lawns on sites with saline soil. It has a long winter dormancy and is subject to mowing scalping.

St. Augustinegrass *(Stenotaphrum secundatum)* (fig. 11.8) is another salt-tolerant warm-season grass. In areas where it is well adapted, it is water efficient and has few pest problems. St. Augustinegrass is used in the most moderate California cli-

mate zones, along the southern California coast or in coastal valleys. It prefers full sun but has a high tolerance for shade. It grows quickly during the summer but slows down during the spring and fall and enters a dormancy period in the late autumn and during the winter. Because St. Augustinegrass is not wear tolerant, it is used for lawns and general purpose turf, but not for high-traffic sports turf. It can become quite dense and difficult to mow.

Kikuyugrass *(Pennisetum clandestinum)* (fig. 11.9), a native of high-altitude equatorial Africa, spreads quickly and thrives in areas with moderate temperatures. It can tolerate heat and will do well under relatively shady conditions. Because of its extremely vigorous growth habit, it is considered to be a weed in coastal and some inland areas of California. It is seldom established as a desired turfgrass. It has a low incidence of disease and is susceptible to cold, but is able to recover quickly from moderate wear or severe injury. Although once considered to be primarily a weed, kikuyugrass is now sometimes managed as a turf species.

Zoysiagrass (*Zoysia* spp.) is adapted to warm climates and is very drought tolerant. Although slow to become established, zoysiagrass is very water efficient with few pest problems. It prefers full sun but will tolerate some shade. Zoysiagrass forms a thick turf, prickly to the touch. Two common species of zoysiagrass are *Zoysia tenuifolia*, a fine-leafed dwarf plant used as ground cover, and *Zoysia japonica*, a Japanese lawn grass that is very drought tolerant. Zoysiagrasses form a dense carpet that may be difficult to mow and scalps easily.

Figure 11.9

Kikuyugrass.

Dichondra *(Dichondra micrantha)* is a warm-season perennial broadleaf ground cover that is best adapted for cool, coastal conditions as a lawn substitute. It will grow in partial shade but does best in full sun. Because dichondra does not tolerate heavy traffic, it is best adapted for small ornamental areas rather than large or highly trafficked lawns or where mowing is difficult. Broadleaf weed invasions are common and can be difficult to manage.

Purchasing Seed, Stolons, and Sod

Purchasing Quality Seed

A lawn is a long-term investment, and the seed you buy is an important element in its success. It is not possible to evaluate seed quality by looking at it. There are differences in lawn seed, and it pays to compare. Some of the information that will help you make a wise choice is printed on seed packages, which should be read carefully. The label must include certain information and should contain the information in the sample below. Label percentages are defined as follows:

% Purity: percentage by weight that is actually seed of the turfgrass specified.

% Germination: percentage of viable (live) seed. The germination percentage was determined on the test date listed, which should be within 12 months of sale or use.

% Crop seed: percentage by weight of crop seeds other than the crop specified. For example, tall fescue may include orchardgrass and ryegrass seed.

% Inert matter: percentage by weight of seed coats, dirt, trash, and anything else that is not seed.

% Weed seed: percentage by weight of all weed seeds and the number of noxious weed seeds present. Avoid seed lots with noxious weeds.

Sample seed label

Lot #TDC-89-07039, ID TRIPLE CROWN DWARF

Kind	% Purity	% Germ.
Monarch tall fescue	49.00	85
Emperor tall fescue	24.50	85
Wrangler tall fescue	24.50	85

% Crop seed: 0.80
% Inert matter: 1.10
% Weed seed: 0.10 no noxious weeds
Tested 6/14, sell by 9/15

John Doe Seed Company
Los Angeles, CA 90021
Limited warranty

Seed blends and mixtures

Grass seed is often sold as a blend of two or more cultivars of the same species (as shown in the sample seed label) or as a mixture of two or more different species. The advantage of a blend is broader tolerance to pests and stress. Mixtures usually include sun-adapted and shade-tolerant species.

Cost comparison of seed sources

The price of seed is only a small portion of the total cost of lawn establishment and maintenance. It is a good practice to buy certified seed because it is guaranteed by the seller to be the kind and cultivar named on the label. Seed quality should be the major factor when selecting among seed sources. Even if the sources are of equal quality, costs may differ. When considering seed lots of similar quality, compare the amount of pure live seed (PLS) in the package. You want to pay only for seed that will grow. To determine the percentage of PLS, use the following formula:

$$\text{PLS} = \text{germination percentage} \times \text{percentage of pure seed} \div 100.$$

Sample PLS calculation

On the sample label, the germination percentage is 85%; the purity of the lot is 98% (the sum of the purities of the individual seeds: 0.49 + 0.245 + 0.245 = 0.98 = 98%). The percentage of PLS is

$$85 \times 98 \div 100 = 83.3\%.$$

To obtain the cost per pound of PLS, divide the price per pound of the packaged seed by the PLS. If the seed in the example above costs $2.25 per pound, the cost per pound of PLS is

$$\$2.50 \div 0.833 = \$2.72.$$

Seeding and Stolonizing Rates

The amount of seed or stolons needed to establish a lawn varies according to the grass species used. Turfgrasses vary in their seed size, number of seed per pound, and growth habit. In general, a lawn will get a good start if seeded at the rate of 15 to 20 viable seed planted per square inch. The seeding rate increases as the seed size increases because there are fewer seed per pound. Excessively high seeding rates can cause problems such as weak, spindly seedlings that are susceptible to disease and slow to form a strong, mature sod. Consult table 11.3 to determine the quantity of seed or stolons to buy.

Purchasing Quality Sod

A number of turf species are available as sod in California, including Kentucky bluegrass, turf-type tall fescues, perennial ryegrass, zoysiagrass, St. Augustinegrass, hybrid bermudagrass, and seashore paspalum. Because each of these sods is best suited for particular uses and geographic areas, select a high-quality, healthy sod that is adapted well to a specific site. Nurseries and sod growers can provide information about the desired sod. Warm-season grass sod usually consists of only one cultivar. Cool-season grass sod, however, often contains several cultivars of the same species. Sod mixtures contain two or more species and usually include both shade-tolerant and sun-adapted grasses.

Table 11.3.

TURFGRASS SEEDING AND STOLONIZING RATES

Seeded grasses		
Grass	**Number of seed (per lb)**	**Seeding rate (lb/1,000 sq ft)**
annual ryegrass	230,000	7–9
bermudagrass (common)	1,750,000	1–1.5
colonial bentgrass	8,000,000	0.5–1.0
creeping bentgrass	7,000,000	0.5–1.0
Highland bentgrass	8,000,000	0.5–1.0
Kentucky bluegrass	2,200,000	2–3
perennial ryegrass	230,000	7–9
red fescue	600,000	3.5–4.5
tall fescue	230,000	8–10
Grasses grown from sod or stolons		
Grass	**Planted as**	**Stolon planting rate (bu/1,000 sq ft)***
bermudagrass (hybrid)	sod or stolons	4–6
seashore paspalum	sod or stolons	3–5
St. Augustinegrass	sod or stolons	3–5
zoysiagrass	sod or stolons	4–6

Note: *1 bu of stolons equals approximately 1 sq yd of sod.

Keep at least one of the tags from the sod so you know what mix the sod is and can purchase replacement sod or seed if bare spots develop in the turf.

When buying sod, make sure it is moist but not too wet. It should have a good green color with no yellowing areas. Sod thickness is important. The soil into which the sod is anchored should measure ¾ to 1 inch thick. Every effort should be made to lay sod within 24 hours after it is cut.

Lawn Maintenance

The wide variety of microclimates and soil types in California makes it difficult to formulate a general program for lawn maintenance. This section covers basic factors in maintaining a lawn. Practices may need modification to ensure success for a given location. Routine lawn maintenance includes mowing, fertilization, irrigation, and weed control. Additional cultural practices that may be necessary during some years are dethatching, aeration, and disease and insect management.

Mowing

An attractive lawn depends on proper mowing, along with other cultural practices such as irrigation and fertilization, to look its best. Mowing at a height and frequency that complement the growth habit of the grass results in a uniform, dense turf that discourages weeds and supports the turf's intended use. Mowing too low weakens grass, causes sod to thin out, encourages weed invasion, makes the lawn more susceptible to pests, and may kill the lawn with time. Mowing too high produces a ragged, unattractive lawn and encourages the buildup of thatch, a spongy layer of plant debris at the soil surface. Mowing frequency is as important as mowing height in maintaining a healthy lawn. It should be

determined by the growth rate of the grass, which in turn depends on climatic conditions and the lawn maintenance program: the more fertilizer and water, the faster the growth rate and the more frequently one will need to mow.

Effect of mowing

The most obvious physical effect of mowing is a decrease in leaf surface area, which decreases a plant's ability to photosynthesize and to produce carbohydrates essential for root, shoot, rhizome, and stolon growth. Higher mowing maximizes photosynthesis and reduces turf stress, as well as increases drought survival through increased root development. Mowing frequency is determined by the species and its seasonal growth pattern. Mow often enough so that no more than one-third of the existing green foliage is removed with any one mowing. If more than one-third of the leaf area is removed during mowing, root growth is temporarily slowed by the plant's inability to produce sufficient carbohydrates. If 50% of existing Kentucky bluegrass foliage is removed by mowing, as little as 35% of the roots can be growing 33 days later.

In cases of severe defoliation, the plant uses stored carbohydrates to produce new photosynthetic leaf surface. However, the carbohydrate reserves are limited and can be seriously depleted if plants are forced to recuperate frequently from mowing that is too severe. Wound hormones are produced every time grass is cut and are followed by the production of enzymes involved in wound healing. Production of these compounds occurs at the expense of food reserves. All mowing is a wounding process, but dull mowers inflict more severe wounds than sharp mowers. Improper mowing practices and equipment progressively weaken turf as the mowing season continues. As a result, the recuperative potential of the grass is reduced, and the turf is predisposed to weeds, diseases, insect pest problems, and drought injury.

Mowing height and frequency

Optimal cutting height is determined by the growth habit of a particular grass. No single mowing height is best for all turfgrasses; mowers must be set differently for each grass. Table 11.1 shows the ranges for optimal mowing heights for California lawns. Within its optimal mowing height range, each grass species will be healthier and have a deeper root system the higher the grass is mowed. Also, within its recommended mowing range, a grass that is cut higher is more tolerant of drought, heat, traffic, shade, disease, and pests than one that is cut lower.

One can determine when and how often to mow a lawn by taking into account the growth rate of the grass during each season and the lawn appearance desired. Cool-season grasses require more frequent mowing in the spring and autumn, since these grasses grow most during this period. Warm-season grasses require more frequent mowing during summer months. Formal, ornamental areas should be mowed more frequently than informal areas.

As a general guide, the one-third rule should be followed: mow often enough so that no more than one-third of the length of the grass blades is removed at any one time. For example, if a turf-type tall fescue lawn is maintained at 2 inches, it should be mowed when the grass height reaches 3 inches. This may mean mowing tall fescue once a week during the spring and every two weeks during the summer.

Grasscycling

Historically, grass clippings made up a surprisingly large portion of California's solid waste stream during the growing season. With few exceptions, it is actually best to leave the clippings on the lawn after mowing. This practice, termed grasscycling, is effective in reducing the amount of waste going to landfills. Grass clippings decompose quickly and release valuable nutrients back into the soil. Grasscycling can be practiced on any healthy lawn as long as the turf is prop-

erly managed. Unfortunately, many people treat a lawn as if it were a crop: overwatering and overfertilizing it to encourage maximum growth, then "harvesting the crop" by bagging the grass clippings and transporting them to a landfill or to composting facilities.

Successful grasscycling requires proper mowing. Cut the grass when the leaf surface is dry, keep your mower blades sharp, and follow the one-third rule. With frequent mowing, you will have short clippings that will not cover the grass surface if left on the lawn and will quickly decompose. A mulching (recycling) rotary mower allows for effective grasscycling since it cuts the clippings up into very small pieces that are easily broken down within the turf.

There are times, however, when grasscycling is not appropriate. Prolonged wet weather, mower breakdowns, or other circumstances that reduce mowing frequency and lead to an excessive volume of clippings probably dictate that the grass clippings should be removed. But do not throw those clippings away! Grass clippings make an excellent addition to a backyard compost pile. Clippings can also be used as mulch to provide weed control and prevent moisture loss in flower beds and around trees and shrubs. In some situations, however, you should not mulch with clippings: clippings can be harmful if they are from an invasive species such as bermudagrass or if herbicides were recently applied to the lawn.

Mower types

There are two basic mower types, reel and rotary (fig. 11.10). A reel mower shears grass with a scissors action and is better for fine-textured turfgrasses or where a low mowing height is desirable. A rotary mower depends on impact cutting with a high-speed rotating blade and is better suited to higher cutting heights and coarser-textured grasses.

Fertilization

Turfgrasses grow best when they have an adequate supply of nutrients. While most of these nutrients are present in soil at a satisfactory level for turfgrass growth and development, a few must be added to the soil as fertilizers. Nitrogen, phosphorus and potassium are the main nutrients applied to turfgrasses on a regular basis.

Timing

Turfgrasses should be fertilized when they are actively growing. The timetable for fertilizing cool-season grasses is almost the reverse of that for warm-season grasses because warm-season species are dormant when cool-season grasses make their most effective use of fertilizer, and vice versa. Turfgrass nutritional needs also change from month to month because of temperature and moisture variations. Cool-season turfgrasses actively grow in the spring and fall and should receive most of their fertilizer in the spring and early fall. Warm-season grasses should be fertilized for the first time when the lawn has fully greened up in the spring. The last application should be 4 to 6 weeks before the likely date of the first frost. Both zoyziagrass and bermudagrass retain better green color in cool weather if fertilized during the fall.

Fertilizer composition and rates

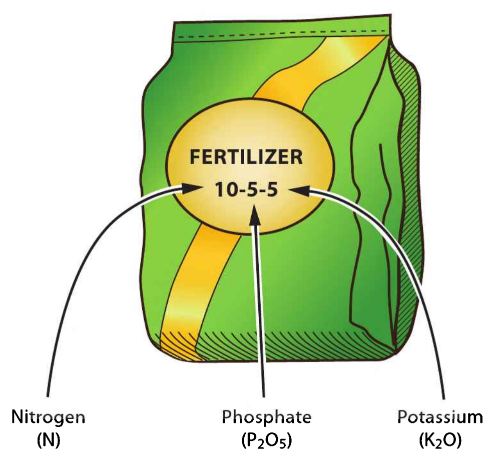
The numbers on a fertilizer bag (e.g., 10-10-10 or 46-0-0) indicate the percentage of nitrogen (N), phosphate (P_2O_5), and potash (K_2O), respectively, in the fertilizer (fig. 11.11). If low levels of phosphorus or potassium are present in the soil, a complete fertilizer (i.e., a fertilizer with all three elements) should be used. If high levels of phosphorus and potassium are already present in the soil, supply nitrogen alone. For most established lawns, nitrogen is the only nutrient that must be supplied on a regular basis. Phosphorus is a vital element in turfgrass establishment due to its role in root system development. Phosphorus

Figure 11.10

Reel- and rotary-type mowers.

Figure 11.11

Sample label of fertilizer bag.



does not readily leach from soil, so applying 1 pound per 1,000 square feet of available phosphate at seeding or sodding and 1 to 2 pounds per 1,000 square feet per year afterward should satisfy the phosphorus requirement of turf. Similar application rates and timing are also recommended for potassium.

Excessive growth stimulated by excessive nitrogen fertilizers can be more detrimental than inadequate fertilization. The source of nitrogen in fertilizers determines whether nitrogen is quickly or slowly made available to plants. Quick-release materials are water soluble and immediately usable by the plant. Slow-release fertilizers make the nitrogen available over time and therefore can be applied less frequently and at higher rates than quickly available sources. In most areas, soluble fertilizers usually last about 4 weeks. A slow-release fertilizer may last 8 to 10 weeks. The portion of slow-release nitrogen is listed on the fertilizer bag as water-insoluble nitrogen (WIN). For example, a 20-10-10 fertilizer with 5% WIN actually has $^5/_{20}$ (or $^1/_4$) of the nitrogen in the slow-release form. A 50-pound bag of this material would provide 10 pounds of total nitrogen, 2½ pounds of which would be slowly available.

For example, a fertilizer label provides the following guaranteed analysis:

- total nitrogen: (5.6% WIN) 16%
- available phosphoric acid: (P_2O_5) 4%
- soluble potash: 8%

To calculate the percentage of WIN (water-insoluble, or slow-release, nitrogen), use the following formula:

$$(\% \text{ WIN} \div \% \text{ total N}) \times 100 = \% \text{ of total N that is WIN.}$$

Using the guaranteed analysis in the sample label above, calculate the percentage of the total nitrogen that is WIN as follows:

$$(5.6 \div 16) \times 100 = 35\%.$$

If no WIN is listed on the fertilizer label, assume that all of the nitrogen is water soluble, or quickly available, unless the nitrogen includes sulfur-coated urea. Sulfur-coated urea fertilizers provide slow-release nitrogen, but the fertilizer label may not list it as WIN. If the fertilizer contains sulfur-coated urea, include that portion as part of WIN when determining the percentage of total nitrogen that is slowly available.

Because fertilizers vary in formula and type, application rates differ. Furthermore, different grass species require varying rates of nitrogen and other nutrients for optimal performance. In general, however,

cool-season grasses perform well receiving about 4 pounds of actual nitrogen per 1,000 square feet per year. Warm-season grasses require ½ to 1 pound of actual nitrogen per 1,000 square feet per growing month. To calculate the amount of material from any given fertilizer, use this formula:

amount of actual nitrogen needed ÷ percentage of nitrogen specified on fertilizer bag.

For example, to apply 1 pound of actual nitrogen to a lawn using a 16-8-8 fertilizer

1 lb ÷ 16 = 6.25 lb actual nitrogen.

Application

Fertilizer should be evenly distributed to avoid striping. To ensure even distribution, it is best to spread half the fertilizer in one direction and the other half at right angles to the first (fig. 11.12). Also, fertilizers should be applied when grass is dry. Fertilizing wet grass may cause leaf burn. If, during fertilization, the fertilizer gets on your driveway or sidewalk, sweep it up and spread it uniformly on the lawn. Do not allow the material to be washed into the storm drain system.

Irrigation

Lawn grasses need water at all stages of growth, from the seedling stage through maturity. Almost every physiological reaction requires water; without it metabolism ceases and the turfgrass plant dies. Water is also essential for proper plant nutrition: mineral elements must dissolve in the soil-water solution before they can be absorbed by roots. Irrigation provides this solution, which is absorbed by roots and translocated through the turfgrass plant, providing a constant supply of food for healthy growth.

Turfgrasses absorb water primarily through their root systems; after using a minute amount, they release most of it through transpiration. If for any reason and to any degree the plant transpires more water than it absorbs, growth is retarded. Transpiration in turf is determined almost entirely by climatic conditions (temperature, humidity, wind, and light), and the need for water over a given period also depends on these factors. Lawn owners must consider these environmental factors when planning an efficient irrigation program.

Irrigation efficiency

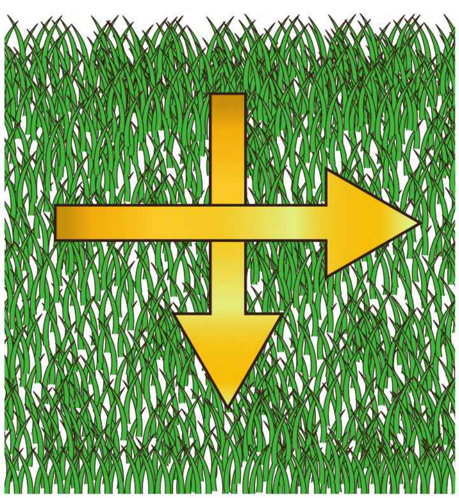
Inefficient irrigation programs, in addition to being wasteful, increase the incidence of diseases and weeds in turf. They also reduce the effectiveness of other turfgrass management practices such as fertilization, mowing, and thatch and pest control. Due to the diversity of soil and climatic factors, however, a single set of recommendations defining irrigation efficiency cannot be given. This section discusses primary factors affecting irrigation efficiency with the hope that a thorough understanding of them will help in developing an efficient irrigation program tailored to individual conditions. After reading this section, refer to the “Lawn Watering Guide” and other irrigation information found in chapter 4, “Water Management.”

Water loss from turf is influenced primarily by climatic conditions. In general, water applied to turf is used or lost through

- deep percolation due to gravitational force

Figure 11.12

Spread half the fertilizer quantity in each direction.



- runoff caused primarily by improper application rates or poor distribution
- evaporation from soil and leaf surfaces
- metabolism and transpiration by the turf plant

Deep percolation and runoff can be reduced by applying the right amount of water at the proper rate and applying it uniformly across the turf. Evaporation and transpiration (the combination of which is known as evapotranspiration, or ET) are influenced by temperature, humidity, wind, and solar radiation. ET increases as temperature, wind, and sunlight (solar radiation) increase and as humidity decreases. Studies also show that ET from a specific turfed site varies among turf species. Under similar climatic conditions, evapotranspiration from sites planted to cool-season turfgrass is generally higher than those planted to warm-season turfgrass. In other words, cool-season turfgrass generally uses more water than warm-season turfgrass.

Lawn water use

Lawns can use 1½ inches or more of water per week in hot, dry weather. Because rainfall in California does not provide this much water, irrigation is necessary during the summer. A lawn should be watered when the soil begins to dry out but before the grass actually wilts. At the wilting stage, areas of the lawn begin to change color, displaying a blue-green or a smoky tinge. Loss of resilience can be observed when grass retains footprints rather than springing up. Ideally, the lawn should be watered before these signs of wilting are obvious. Cool-season grasses usually become semidormant in the hottest part of the summer, returning to full vigor in cooler fall weather. Regular, deep watering is necessary to keep the lawn green through the summer.

To irrigate a lawn efficiently, in addition to climatic factors, soil type (texture) and its water-holding capacity must be also considered. Water-holding capacity depends on soil texture. The heavier (more clayey) a soil is, the higher its water-holding capacity (for more details, see chapter 4, “Water Management”).

Light sprinkling of the turf surface is harmful because it encourages root development near the soil surface. Shallow root systems require frequent watering to keep the surface wet, which creates an ideal environment for weeds and diseases. Therefore, water consistently and deeply. Encouraging deep root growth by infrequent heavy irrigation maximizes water-use efficiency and turfgrass quality. Avoid runoff and puddling as much as possible by cycling irrigations until the desired amount is applied. The best time of day to water a lawn is early morning (2 a.m.–8 a.m.) when water pressure is often at its highest and winds are minimal. Also, evapotranspiration is minimal at this time, making water-use efficiency optimal. Early evening or night watering is not recommended because during cool nights, wet blades and thatch are highly susceptible to disease development.

Drought tolerance

Turfgrass species vary greatly in their tolerance to drought stress. Warm-season turfgrasses are much more drought tolerant than are cool-season grasses. Among cool-season grasses, tall fescue is the most drought tolerant. The more drought-tolerant turfgrasses should be considered when it is known before turf establishment that an area will be irrigated only on a limited basis. It should be noted that several environmental factors also contribute to drought tolerance. Generally, deep-rooted grasses growing in a deep soil with good subsoil moisture can remain green for extended periods despite lack of irrigation. Once soil moisture in the root zone is depleted, however, the turfgrass cannot survive for long. Deep-rooted turfgrasses, such as the tall and hard fescues, growing in dry areas where rain or irrigation may wet only the top few inches of soil may not exhibit as much drought tolerance as the same grasses grown in a soil with ade-

quate subsoil moisture but infrequent rain or irrigation.

A drought-tolerant turfgrass does not necessarily provide a lush green turf under limited irrigation. Most drought-tolerant turfgrasses go dormant, lose color, and stop growth under drought situations. They can, however, resume growth and green up when moisture becomes available. Turfgrasses that are not drought tolerant have a much shorter drought-induced dormancy period before they die than do drought-tolerant species.

Best management practices for irrigation

Attention to the following best management practices for turfgrass irrigation will greatly reduce water waste and further increase water efficiency and conservation efforts:

- Separately irrigate slopes, low spots, and other areas where water behaves differently than on flat surfaces.
- Install check valves to eliminate drainage to the low spots in a pipe system when water is turned off.
- Use proper irrigation system design and relocation of sprinkler heads to eliminate overflow onto paved areas and sidewalks.
- Use the same type of sprinkler head throughout a turf area (matched precipitation-rate heads) to ensure a more uniform application rate.
- Avoid applying water too fast, too long, or nonuniformly. Try to apply water at the same rate that it infiltrates into the soil.
- Modify irrigation scheduling so that water can be applied in several short repeat cycles instead of a single long irrigation.
- Irrigate in early morning when wind and evaporation losses are lowest.
- Reduce irrigation of shaded areas relative to unshaded areas.
- Base irrigation timing on inspection of the turf; that is, look for dry spots rather than allowing the passage of a standard amount of time.
- Immediately repair leaky pipes, heads, valves, and so on.

Dethatching

In addition to the routine maintenance practices discussed above, it may be necessary to remove thatch in some years, depending on the turfgrass species (see table 11.1). Thatch is the tightly interwoven layer of living and dead stems, roots, stolons, and rhizomes that exists between the green blades of grass and the soil surface (fig. 11.13). This layer of decomposing organic matter accumulates on the soil surface in an innocuous fashion. During the earliest stages of development, when it is less than ½ inch thick, thatch can actually be beneficial because it increases the wear tolerance of the turf by providing better dissipation of compaction forces, reduces weed populations by limiting germination conditions, reduces water evaporation by blocking sunlight and air exchange with the soil surface, and insulates crown tissue, protecting it from frost and traffic damage.

Thick thatch layers cause problems, however. The moist microclimate created by a thick thatch layer favors fungal growth and allows disease-causing microorganisms to live and sporulate. The probability of insect pests overwintering is increased by the insulating effect of thatch. Soilborne fungi and pest insects often escape chemical controls that are unable to penetrate the thatch layer. The thatch layer also pre-

Figure 11.13

Thatch.

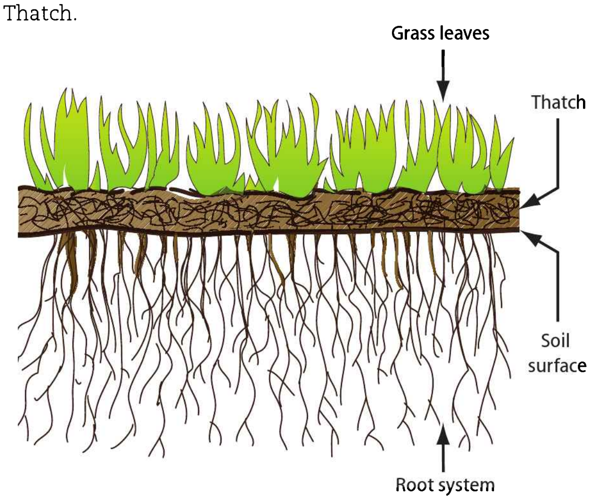
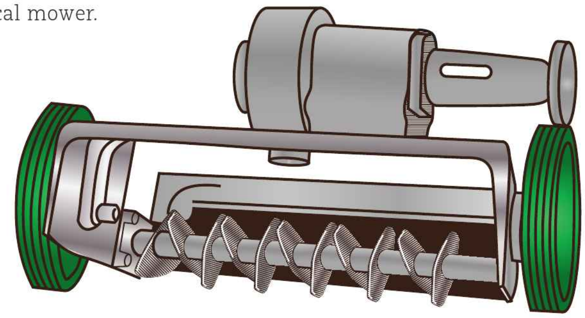


Figure 11.14

Vertical mower.



vents adequate water infiltration, reducing root growth and increasing the potential for drought stress. When thatch layers are kept moist, roots tend to develop in this zone, and crown regions of the individual turfgrass plants tend to be elevated in the thatch. This elevation of the crown region away from the soil leads to increased exposure to temperature extremes and to a greater probability of stress damage. Interception of fertilizer by thatch layers produces erratic responses to fertilization. In some cases, microorganisms in the thatch tie up the applied nitrogen, making it unavailable to the turfgrass.

Thatch builds up when organic matter accumulates on the soil surface faster than it can decompose. Some of the many reasons for the imbalance between the rates of accumulation and decomposition are excess nitrogen fertilizer, grass species, excess irrigation, chemical use, and soil type. There is no simple method for controlling thatch, but preventive programs for thatch reduction should be built into any maintenance program. Labor-intensive dethatching may be necessary at times. Preventive thatch management involves proper nutrition, aeration, mowing, and irrigation practices. Moderate use of nitrogen with more-frequent, small applications appears to decrease thatch buildup. Aeration and topdressing of turfgrass speeds up thatch decomposition because aerobic microorganisms involved in thatch decomposition benefit from improved oxygen levels as much as turfgrass does. Light soil topdressing can inoculate the thatch layer with microorganisms and improve moisture retention in the thatch layer, which increases microbial activity.

If the thatch layer in a lawn is more than ½ inch thick, dethatching will be beneficial. Vertical mowers, or verticut machines, can be rented for this purpose (fig. 11.14). Verticutting rakes the soil surface and leaves the thatch debris on top of the lawn. This debris should be removed. If overseeding is planned, it should follow the verticutting or aerating process, because the grooves cut in the soil provide good soil contact for new seed. It is critical that dethatching be done when plants can recover quickly from the treatment. Kentucky bluegrass and other cool-season grass lawns should be dethatched in early fall or early spring. Warm-season grasses may be dethatched while they are green and actively growing.

Aeration

If the soil is heavy and compacted or if thatch buildup is a problem, aeration may be beneficial. Roots need oxygen as well as water and nutrients. Compacted soil restricts the absorption of water and the exchange and replenishment of oxygen from the atmosphere to the soil. Soil compaction is a stress that does not directly kill the turfgrass. Instead, it predisposes turfgrass to a variety of other stresses that can cause injury. Although soil compaction may be invisible, it is certainly very damaging to the turf plant and must be addressed in a lawn management program.

Aeration is done best by a machine that forces hollow metal tubes into the ground and brings up small cores of soil that are left lying on the surface (fig. 11.15). The soil should be moist (not too wet or too dry) when this is done. Simply punching holes with a spiked roller may improve water retention, but this practice may also increase compaction in the soil. Aeration cores left on the surface will eventually

break down, and small particles will move down into the thatch layer. Additions of soil and microbes into the thatch through the aeration process help create an environment conducive to faster thatch decomposition.

Weed Control

Nearly all weeds that infest lawns in California can be controlled by currently available herbicides. However, while chemical weed control should not be ruled out, proper lawn management can prevent a significant portion of weed problems and should be considered the foundation of weed control.

Weeds are generally defined as plants growing where they are not wanted. Thus, a tall fescue lawn is perfectly acceptable, while tall fescue clumps growing in a bluegrass lawn may be considered weeds. Generally, weed growth in a lawn is encouraged by inadequate turf cover, that is, a thin lawn with bare spots. Environmental conditions, including excessive traffic, and poor management practices are the primary causes of thin lawns. Long periods of drought, temperature extremes, overirrigation, inadequate fertility, and poor mowing practices can lead to thinning of a turf stand. Rodents (gophers, moles, voles), insects and turf diseases, misuse of herbicides, and heavy foot traffic can also destroy sufficient turf to leave a stand vulnerable to weed invasion.

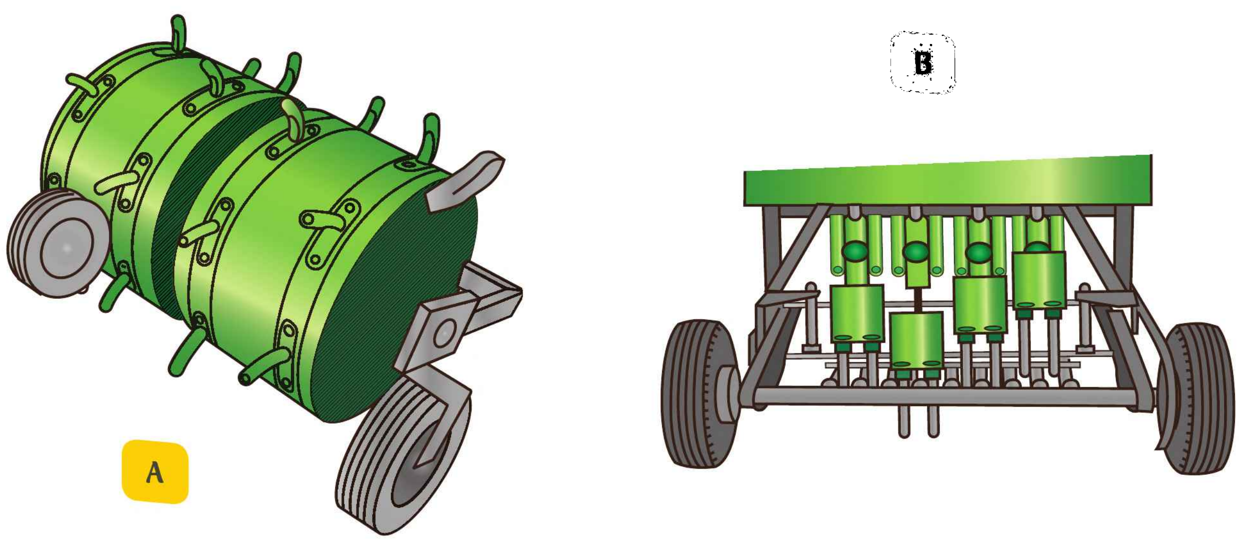
Developing a weed control management program

Knowledge of the most appropriate grass for a given situation and the prevailing weed species for the geographical area where the grass will be grown is the most valuable information for lawn weed control. Armed with such information, a homeowner can create an environment and a management program that favor the desired grass over weeds. A lawn grass adapted to the locality is the best insurance for a healthy, dense lawn. A blend of adapted cool-season cultivars is preferable to a single cultivar, since monostands (a turf stand composed of a single cultivar) are more limited in the range of conditions under which they perform well. At least three cultivars of a cool-season turfgrass species should be used in a lawn grass blend. By contrast, warm-season turfgrasses are always planted in monostands, since cultivars within each species are often sufficiently morphologically varied to provide less than satisfactory visual results.

In addition to proper turf species and cultivar selection, a management program of proper irrigation, fertilization, mowing, and aeration minimizes weed seed germi-

Figure 11.15

Coring aerifiers. (A) Roller-type aerifier. (B) Piston-driven aerifier.



nation and maximizes the competitiveness of lawn grasses. Nevertheless, there are situations where, regardless of good management, a lawn is invaded by weeds. If the weeds are not abundant, removing them by hand-pulling or other mechanical methods is the best approach. There are currently no effective biological means of lawn weed control. If a weed invasion is extensive, chemical control may be the only practical, effective way to eliminate it. Herbicides (weed killers) should be applied at the time of year and the rates recommended on the product label. Careless application of lawn herbicides can damage desirable grasses or adjacent ornamental plantings. In fact, although many lawn weeds invade other home landscapes as well, appropriate herbicides for each location are different. Herbicides used to control broadleaf weeds in grasses, for example, can injure or kill most ornamentals, while herbicides that control grassy weeds in ornamentals injure lawn grasses. In general, chemical control of broadleaf weeds in lawns is relatively easy; controlling grassy weeds in lawns, however, is much more difficult, with choices of herbicide for this purpose rather limited.

Types of lawn weeds

Lawn weeds are of three basic types: broadleaf (such as dandelions, clover, oxalis, plantain, spurge, henbit, and chickweed); grass (such as annual bluegrass, smooth or hairy crabgrass, dallisgrass, and bermudagrass); and sedges (yellow or purple nutsedge). Weeds may also be annual, biennial, or perennial.

Annual weeds, as their name suggests, germinate from seed, grow, mature, produce seed, and die in less than 12 months. Crabgrass, goosegrass, and prostrate spurge are examples of summer annuals. Seed germinate in spring, and mature plants die in late fall with the first frost. Such weeds are effectively controlled with preemergent herbicides, that is, chemicals applied to an established lawn to prevent germination and emergence of weed seeds or to kill newly germinated seedlings. Winter annual weeds (such as shepherd's purse and annual bluegrass) start their life cycle in the fall and complete it the following spring or summer; preemergent herbicides to control these are therefore applied in late summer.

Biennial weeds require 2 years to complete their life cycle. Only a few biennial weeds (e.g., henbit, cudweed, and filaree) invade California lawns. Chemical control of these weeds is most effective during the first year of growth; during the second year, herbicide application before bloom is most effective.

Perennial weeds live more than 2 years. Clover, dandelion, field bindweed, plantain, and oxalis are typical broadleaf weeds in California lawns. Among the most difficult perennial grassy weeds invading lawns are dallisgrass, bermudagrass, velvetgrass, and kikuyugrass. All perennial weeds respond best to selective herbicides during the active growth and seedling stage, usually in early spring or late fall.

A detailed description of lawn weeds and herbicides is beyond the scope of this chapter. Several UC IPM Pest Notes are available online at ipm.ucdavis.edu/homegarden, as well as a complete UC interactive program (UC Guide to Healthy Lawns, ipm.ucdavis.edu/TOOLS/TURF/), which contains detailed, practical, up-to-date information on lawn weed control. Also see chapter 8, "Weed Science."

Disease Control

Although uncommon, diseases are perhaps the most difficult-to-control pest problem affecting California lawns. Diagnosis can be challenging and perplexing. While weeds, insects, and rodents can be seen with the naked eye, and maladies related to the environment and management can often be identified relatively quickly, lawn diseases often go unrecognized until considerable injury has occurred.

Types of lawn diseases

In California, almost all lawn diseases are caused by fungi: low, threadlike micro-

scopic organisms that lack chlorophyll, are incapable of manufacturing their own food, and live off other plants or animals. Most lawn fungi produce spores (seedlike units) or other forms (sclerotia) that may be spread by wind, water, mowers and other equipment, people's shoes, and infected plant material such as grass clippings. Since almost all lawn fungi are microscopic, however, their presence can be observed only in the responses of the grasses they infect. Diagnosis of a specific lawn disease (and its causal fungus) is complicated, as symptoms of infection vary widely and depend on factors such as turf species, height of cut, time of year, local climate, and the presence of other pests. Typical symptoms caused by lawn fungi include leaf spots; white, yellow, or black powdery growth on leaf surfaces of the grass; and small to large rings, crescents, spots, or patches of discolored or dying lawn. Other typical symptoms of lawn diseases are frog-eye patterns (a circular area of dead grass with healthy grass in the center), rotted crowns and roots, yellow leaves, stunting, and wilting. Affected lawn areas can become discolored and lose density quickly. Diseases are often diagnosed by associating symptoms with a causal agent and less often by the presence of signs of the pathogen, such as whitish cottony growth or small, hard, dormant structures (sclerotia).

Precise instructions for identifying lawn diseases are beyond the scope of this chapter. The UC Guide to Healthy Lawns, as well as other publications listed in the bibliography, provides color photographs of disease symptoms and characteristic growth and infection criteria for individual fungi.

Management and prevention

Models of disease transmission—sclerotia and threads (mycelium)—require moisture and a favorable temperature for growth. New threads grow over plant surfaces or in the plant itself, causing infection. That is why grass diseases are most common during rainy seasons, when moisture remains on leaves for long periods of time or when soil moisture accumulates and stands. To avoid too much moisture from irrigation, it is better to water during early morning than in late evening; deep, infrequent watering is also better than shallow, frequent irrigation, and adequate soil drainage is essential in new plantings. The effect of temperature on disease varies: Some diseases are favored by warm temperatures; others are destructive during the cooler months of the year.

All turfgrass diseases are easier to prevent than to cure. Minimizing the possibility of disease requires planting the right grass cultivar for a particular climate at the recommended rate and time of year. Weakened, nonadapted grasses are more susceptible to certain turf-attacking fungi as well as such stresses as drought and hot, dry winds. Appropriate cultural practices, such as proper mowing, adequate fertilization, judicious and timely irrigation, and frequent aerification, help prevent disease by encouraging a vigorously growing turf. In general, properly maintained turfgrass is less severely damaged by disease and is able to recover more quickly than a poorly maintained grass.

Among cultural practices, nitrogen fertilization plays a particular role in disease prevention. While too much nitrogen results in soft, lush growth, a condition favorable to some diseases, nitrogen deficiency leaves grass susceptible to others. If cultural practices are not sufficient to control disease, fungicides are recommended. These are usually most effective when applied before disease becomes severe. Once disease becomes severe, fungicide must usually be applied more frequently and at a higher rate.

For an updated list of California lawn fungicides, consult the appropriate UC publications listed in the bibliography or at the UC IPM Guide to Healthy Lawns, Pest Notes, and Guides to Turfgrass Pest Control websites.

Insect Control

Insect damage to lawns often resembles the symptoms produced by disease, drought, poor soil conditions, or other factors. Before applying any insecticide, therefore, it is best to make sure insects are causing the observed damage.

Insects that damage lawns

Only a few of the many insects naturally found in a lawn cause serious damage. Some insects are beneficial, while others, although potential pests, cause damage only in large numbers. A healthy, vigorous lawn is less likely to have insect problems than a lawn in poor condition, and it can also outgrow most infestations. The most important principle of insect pest management in lawns, therefore, is to promote vigorous growth to enable grass to withstand moderate insect feeding. In most cases, a healthy lawn in California requires little, if any, insecticide application.

Although insects are not a common cause of residential lawn damage in California, on rare occasions certain species may damage or even kill turfgrasses. Insect feeding can cause grass to turn yellow or brown, or die, especially if the grass is already stressed. Damage usually begins in small, scattered patches, which may merge into large dead areas. However, lack of proper cultural care and use of inappropriate grass species in a particular location are more likely responsible for unhealthy or dying lawns than insects. Disease-causing pathogens, excessive or inappropriate use of chemicals such as fertilizers and herbicides, and dog urine also produce damage resembling that of insects.

Insects that may cause damage in California lawns include various caterpillars that feed on grass roots, crowns, and leaves; white grubs, which are the larvae of scarab beetles, such as the black turfgrass ataenius and masked chafers; billbugs, which are weevils with white, grub-like larvae; and chinch bugs, which are true bugs in the order Hemiptera. Each species produces somewhat different damage symptoms and must be managed differently. Leafhoppers may also occur in lawns, sometimes causing yellowing of leaf blades, but they rarely occur in numbers justifying treatment. Many other insects may be observed while examining grass.

Biological and chemical control

In the rare instances where cultural practices do not prevent lawn damage by insects and treatment is warranted, UC IPM Pest Notes available online can provide up-to-date recommendations on biological and chemical insecticides for California lawns. Among biological materials, the microbial insecticide *Bacillus thuringiensis* and insect-killing nematodes are the most promising. These are not chemicals and have minimal negative impact on beneficial insects and the environment.

If the combination of good lawn management practices is unable to reduce lawn insect pest activity, chemical insecticides may be called for. In such cases, identification of the insect responsible is paramount to choosing the correct insecticide. The timing of insecticide application is also often as important as insecticide choice. Most insecticides give better control on the younger insect stages; to determine when and where these stages occur, inspect the lawn regularly. In California, preventive insecticide application is not recommended. The negative environmental impacts of such treatments far outweigh the rare occasions of actually preventing an insect outbreak in home lawns.

Granular insecticides work faster when watered into turf immediately after application. If sprays are used, turfgrass should be adequately irrigated and allowed to dry before application to control insects feeding on grass blades, stems, and crowns. This allows an insecticide to remain on turfgrass and be effective as long as possible before another irrigation. If sprays or granules are used to control insects such as white grubs, billbugs, or caterpillars

that feed belowground, turf should be heavily irrigated after application to carry the insecticide into the soil.

Certain insecticides may injure turfgrass if used at the wrong stage of turfgrass development or when the temperature is too high. Injury may also result from excess material or the wrong chemical formulation. Product label directions should therefore always be followed.

Detailed discussion of specific lawn insect identification, damage symptoms, management, and control is beyond the scope of this chapter. UC publications, as well as the web-based publications by UC IPM (see the bibliography) are the best tools for identifying each insect species.

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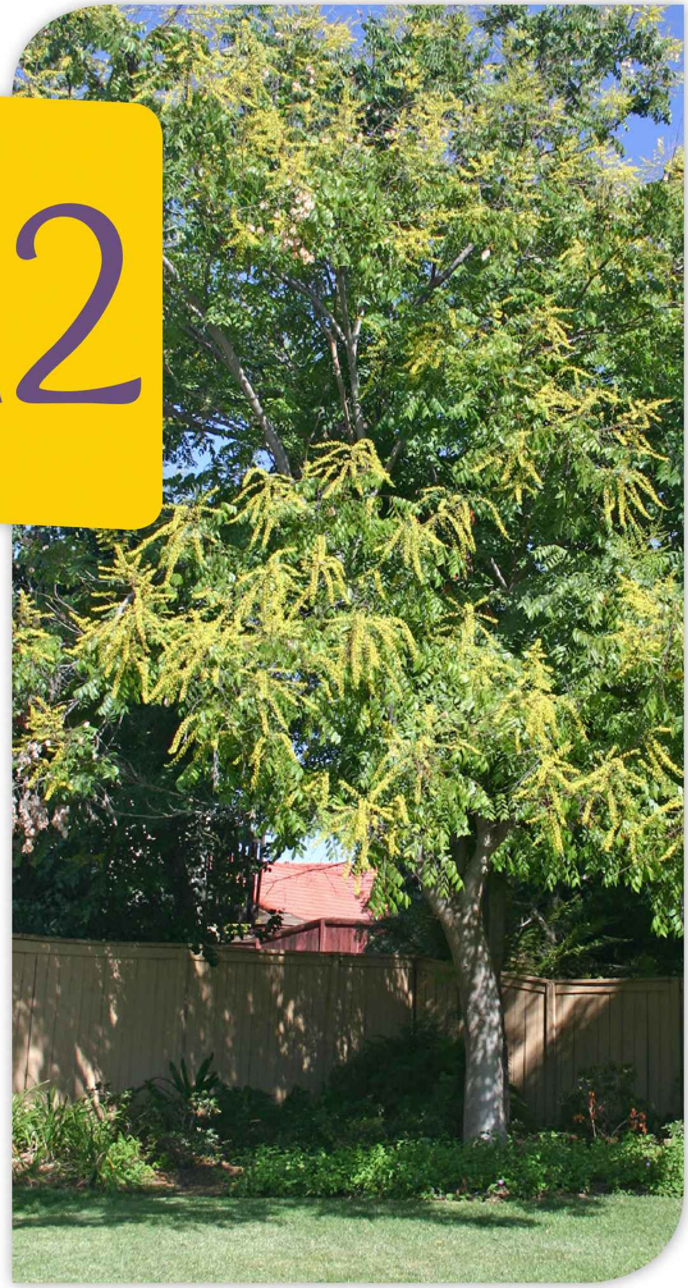
Woody Landscape Plants 12

Donald R. Hodel and Dennis R. Pittenger



Learning Objectives

Learn principles of selecting woody landscape plants.

Learn how to plant woody landscape plants.

Learn how to make pruning cuts; train young trees; and prune mature broadleaf trees, conifers and other narrowleaf evergreens, hedges, broadleaf shrubs, ground covers, vines, garden roses, and palms.

Learn correct fertilization practices for woody plants.

Learn how to design and maintain the landscape for fire protection.

Learn details of selecting, planting, and maintaining roses and palms.

Woody Landscape Plants

Plants in the urban landscape modify the environment, softening its harshness and making it more livable. Landscaping also adds significantly to the dollar value of commercial and residential property. However, in order to fully realize the potential amenities and benefits that landscaping can provide, one must select, install, and maintain plants with the utmost care. This chapter addresses the key concepts of these topics.

Selection of Landscape Plants

Gardeners can minimize maintenance and future problems in the landscape by selecting the right plant for the right spot. Consider functional uses, growth habit, environmental tolerances, and site adaptation when selecting plants. Also consider whether a plant could become invasive of natural areas should it escape from your property; for more information, see chapter 8, "Weed Science."

Functional Uses, Benefits, and Costs

Plants have many functions in the landscape that depend on the species and its inherent growth characteristics, including shape, size, color, texture, seasonal characteristics, and flowering and fruiting habits. Among these uses are wind protection and modification, noise reduction, air purification, dust collection, water runoff and erosion control, environmental modification, and energy conservation. Landscape plantings, particularly well-placed trees, may lower summer air temperatures by intercepting sunlight, screening reflecting and radiating surfaces, and transpiring water vapor into the atmosphere. Plant masses placed around a building may reduce wind movement against walls of the structure. Deciduous trees can provide these cooling benefits and allow winter solar energy collection after their leaves drop. Urban landscapes have been shown to reduce atmospheric carbon dioxide (CO_2) in two ways: storing it in leaves and stems and reducing the demand for heating and air conditioning, reducing fossil fuel emissions from heating buildings and electric power generation. Plants can also direct traffic, define space, develop a sense of privacy, screen unsightliness, provide security, serve as wildlife refuges, and enhance aesthetic and ornamental qualities of open space and structures.

Urban landscape plantings also generate costs, including irrigation water, pruning and green waste disposal, repairing pavement damage caused by roots, flooding caused by leaf litter and other plant debris clogging storm sewers, and air pollution. Many landscape plants, including many trees, emit various volatile organic compounds, some of which can contribute to ozone formation. Species vary widely in their specific emissions and the potential to increase ozone formation. However, it requires large-scale mass plantings of species that emit relatively high amounts of ozone-forming emissions in order to significantly influence atmospheric ozone levels.

Growth Habit and Size

The ultimate size and rate of growth are important considerations when selecting woody landscape plants. Plants that become too large are a common problem in the landscape, and, as the typical residential lot continues to shrink, oversized plants will be increasingly troublesome. Oversized plants can block views, conflict with overhead utility lines, crowd out other plants, ruin designs, and damage hardscape (patios, sidewalks, curbs, etc.), as well as be hazardous, difficult to care for, and expensive to remove. Although homeowners often desire an instantly mature landscape, they should be aware that fast-growing plants, especially trees, are generally short-lived and often have invasive roots and weak or brittle wood that is prone to breakage. Patience is a gardener's greatest virtue, and the homeowner will be duly rewarded by selecting for permanence in the landscape and using species noted for their slow or moderate rate of growth and long life.

Plant growth features such as seasonal characteristics of leaves, flowering and fruiting habit, presence of thorns, and branch and canopy structure are important considerations for placement in the landscape and future maintenance. A tree with excessive leaf, flower, and fruit litter could be annoying and hazardous in high-use areas like sidewalks, patios, and decks. The same tree placed away from high-use areas and with a ground cover beneath it to absorb litter is less problematic. Remember that, because of branching habit and growth characteristics, some species require more frequent and intense levels of training and pruning to achieve the desired form.

Environmental and Pest Tolerances

The environmental adaptation of a species to a particular site is another important consideration. Simply because a local nursery stocks the plant does not signify that the plant is adapted to the climate and soil of the area. Consider the wind, exposure (light), soil type, moisture, humidity, pests, fire, and extremes of temperature that your site offers in comparison to the needs and tolerances of the plant species being considered.

Susceptibility to common pests should also be considered when selecting plant species. Choose a pest-resistant or pest-tolerant cultivar or selection whenever possible. Unfortunately, the availability of these cultivars or selections is limited. A list of certain plants with known resistance or susceptibility to Verticillium wilt, a serious soilborne fungal disease, is found in table 12.1.

General Tips

Advance planning is necessary to integrate functional uses, growth characteristics, and environmental tolerances in a landscape and at the same time attain an aesthetically pleasing result. Successful landscaping requires a knowledge of plant materials, careful assessment of the landscape site, and development of appropriate design solutions.

To become familiar with plant materials, especially how they will perform and look when mature, visit your local parks, botanical gardens and arboreta, street plantings, private gardens, and nurseries. Inquire and consult with people who live or work in or near these places. Although nurseries are good sources of information, remember that their stock is usually not full grown, and the ultimate size and shape of the plants may not be represented accurately. Also, as noted above in the discussion on environmental and pest tolerance, finding a plant in a local nursery does not signify that the plant is suited for the scale and other factors associated with urban and suburban residences.

Consult the numerous references available in most libraries about selecting and caring for landscape plants. A good general guide for all of California is the *Sunset Western Garden Book* (Brenzel 2012) and regional and local references are available for most parts of the state. For trees, the Local Government Commission's tree guideline

Table 12.1.

RESISTANCE AND SUSCEPTIBILITY OF SELECTED ORNAMENTAL PLANTS TO VERTICILLIUM WILT *(VERTICILLIUM DAHLIAE* OR *V. ALBO-ATRUM)*.

Scientific name	Common name
Resistant or immune families	
Cactaceae	cactus family
Graminae	cereal grains, corn, grasses, milo, sorghum, others
Gymnospermae	gymnosperms (cypress, fir, ginkgo, larch, juniper, pine, sequoia, spruce, others)
Monocotyledoneae	monocots (bamboo, banana, gladiolus, grasses, iris, lily, onion, orchids, palms, others)
Polypodiaceae	fern family (ferns)
Resistant or immune trees and shrubs	
Arctostaphylos spp.	manzanita
Betula spp.	birch
Buxus spp.	box
Carpinus spp.	hornbeam
Ceanothus spp.	ceanothus
Cercidiphyllum japonicum	katsura tree
Cistus corbariensis	white rock rose
Cistus salvifolius	sage-leaf rock rose
Cistus tauricus	rock rose
Citrus spp.	orange, lemon, grapefruit, others
Cornus spp.	dogwood
Crataegus spp.	hawthorn
Eucalyptus spp.	eucalyptus
Fagus spp.	beech
Ficus carica	fig
Gleditsia spp.	locust
Gleditsia triacanthos	honey locust
Hebe anonda	hebe
Hebe × franciscana	hebe
Hebe × menziesii	hebe
Hebe salicifolia	hebe
Ilex spp.	holly
Juglans spp.	walnut
Liquidambar styraciflua	liquidambar, sweetgum
Malus spp.	apple, flowering crabapples
Morus spp.	mulberry
Nerium oleander	oleander
Platanus racemosa	Western sycamore
Platanus spp.	plane tree
Pyracantha spp.	pyracantha, firethorn
Pyrus spp.	pear
Quercus spp.	oak
Salix spp.	willow

Table 12.1. cont.

RESISTANCE AND SUSCEPTIBILITY OF SELECTED ORNAMENTAL PLANTS TO VERTICILLIUM WILT *(VERTICILLIUM DAHLIAE* OR *V. ALBO-ATRUM)*.

Scientific name	Common name
Sorbus aucuparia	European mountain ash
Tilia spp.	linden
Umbellularia californica	California laurel
Susceptible trees	
Acer negundo	box elder
Acer spp.	maple
Ailanthus altissima	tree-of-heaven
Carya illinoensis	pecan
Catalpa spp.	catalpa
Ceratonia siliqua	carob
Cercis canadensis	redbud
Cinnamomum camphora	camphor tree
Cladrastis lutea	yellow wood
Cupaniopsis anacardioides	carrotwood
Diospyros spp.	persimmon
Elaeagnus angustifolia	oleaster, Russian olive
Ficus benjamina	weeping fig
Ficus retusa	Indian laurel
Fraxinus spp.	ash
Koelreuteria paniculata	golden rain tree
Liriodendron tulipifera	tulip tree
Magnolia grandiflora	Southern magnolia
Nyssa sylvatica	black gum, pepperidge
Olea europaea	olive
Persea americana	avocado
Pistacia chinensis	Chinese pistache
Prunus spp.	almond, apricot, cherry, peach, plum, prune
Robinia pseudoacacia	black locust
Schinus molle	California pepper tree
Schinus terebinthifolius	Brazilian pepper tree
Ulmus spp.	elm
Susceptible ground covers, shrubs, and vines	
Berberis (Mahonia) spp.	barberry
Campsis radicans	trumpet creeper
Capsicum spp.	pepper
Carpobrotus edulis	ice plant
Cistus ladanifer	spotted rock rose
Cistus palhinhai	rock rose
Cistus × purpureus	orchid-spot rock rose
Cotinus coggygria	smoke tree
Dodonaea viscosa	hopseed bush

Table 12.1. cont.

RESISTANCE AND SUSCEPTIBILITY OF SELECTED ORNAMENTAL PLANTS TO VERTICILLIUM WILT *(VERTICILLIUM DAHLIAE* OR *V. ALBO-ATRUM)*.

Scientific name	Common name
Erica spp.	heather
Fremontodendron spp.	flannel bush
Fuchsia spp.	fuchsia
Hebe bollonsii	hebe
Hebe × *carnea* 'Carnea'	hebe
Hebe lewisii	hebe
Jasminum magnificum	angel wing jasmine
Jasminum mesnyi	primrose jasmine
Lampranthus spectabilis	ice plant
Ligustrum spp.	privet
Nandina domestica	sacred bamboo
Parthenium argentatum	guayule
Rhaphiolepis indica	Indian hawthorn
Rhaphiolepis umbellata	yeddo hawthorn
Rhus integrifolia	lemonade berry
Rhus spp.	sumac
Rosa spp.	rose
Rosmarinus officinalis L.	rosemary
Syringa vulgaris	lilac
Viburnum spp.	viburnum, wayfaring-tree, others

Source: Adapted from McCain et al. 1981, pp. 3–4, 7, 8.

publications listed in the bibliography of this chapter are additional resources. Also, some UCCE county offices have prepared lists of trees and other landscape plants recommended for local conditions. For more information on pests of woody landscape plants, see *Pests of Landscape Trees and Shrubs* (Dreistadt 2004) and the UC IPM Pest Notes, ipm.ucdavis.edu/PMG/menu.homegarden.

Selecting Plants in the Nursery

The quality of the trees, shrubs, vines, and ground covers selected in a nursery can be just as important as species selection, site evaluation, planting, and maintenance in determining their success in the landscape. Carefully inspect plants from top to bottom before purchase to ensure that they meet crown, trunk, and root standards and are healthy, vigorous, and free from injury, disease, and pests.

Nurseries stock mostly container-grown plants. Container-grown plants can be transplanted successfully any time during the year in all areas of the state except those that experience extended periods of subfreezing weather (see the section "Planting," below). During the dormant winter season, however, a variety of deciduous, woody fruit, shade, and ornamental trees and vines are usually readily available bare-root. If handled and planted properly, bare-root plants are normally less expensive and grow just as well as container-grown ones, and their roots are easier to inspect.

Some ground covers, vines, and low-growing shrubs are available as rooted cuttings in flats. These can be transplanted any time of the year; however, successful transplanting is more likely during the fall or spring,

Foliage, Stem, and Trunk Characteristics

The aboveground portions of plants are the easiest to inspect. Check the crown of leaves and shoots for health, turgidity, presence of disease or insects, and shape and structure. If the plant is staked, untie it and see if it bends over sharply at the soil line or if the trunk is loose in the soil, both of which indicate poor trunk and root development.

If trees were grown in the nursery with adequate space and without staking or severe pruning, they are usually capable of supporting themselves, even in wind. They should return to an upright position when bent down by the wind or hand if they have developed proper crown-to-trunk and crown-to-root ratios, trunk taper, and branch distribution. Proper development of these characteristics ensures even distribution of wind stress and less breakage and damage. Plants are often crowded in nurseries during production and may not attain these desirable characteristics.

The height and size of the crown should be in moderate proportion to the caliper of the trunk and size of root mass. If the plant has been grown in a series of containers for many years, the crown may be too large or too small in proportion to the roots. Woody plants in this condition require relatively high postplanting care. Judicious thinning or pruning will reduce the crown-to-root ratio and improve moisture and nutritional levels, lessening the need for continued high levels of care.

A tree's trunk should be tapered, wider at the bottom and more slender near the top, bending only along a section near the ground when subjected to sufficient stress. Tapered trunks distribute wind loads evenly in their lower portions, minimizing the possibility of breakage or damage. Excessive crowding, staking, and severe pruning can produce trees without proper taper, leading to trunks that break easily or remain bent over after the wind has stopped.

Branches along the trunk of a tree, especially a young one, distribute wind stress evenly. The crown should have branches placed along the trunk so that about half of the foliage is on branches originating in the upper third of the trunk and the other half of the foliage is on branches originating in the lower two-thirds of the trunk. Lower branches on young trees not only help to distribute stress more evenly but also help the tree attain greater caliper and taper. Lower branches should be kept short in relation to higher, permanent, scaffold branches and can be removed altogether with time. Future, main scaffold branches should be well spaced both up and down the trunk as well as around it and should form wide angles at the point of attachment.

Plants from flats should be growing and have considerable green foliage. The plants should be established in the flat but not overgrown so that individual plants are not distinguishable.

Roots

A healthy, well-developed root system is essential to establishing a plant successfully in the landscape. Carefully remove a plant from its container to inspect the roots. Turn plants in 1-gallon containers upside down and, while holding the stem between the fingers with the hand spread flatly against the soil surface, tap the rim of the pot gently onto a solid object until the root ball slides out easily. Carefully pick up plants in 2- and 5-gallon containers at the base of the stem, gently tap on the container rim, and gently push the container down to expose the roots. If a plant this size begins to pull out of the soil ball as it is being lifted, it is a poorly rooted specimen. Similarly, plants in even

larger containers can be laid on their side and removed from the container to inspect root development. If the roots are not growing to the bottom of the container, the plant is poorly rooted and was possibly recently repotted from a smaller container.

To inspect the roots of ground covers in flats, carefully place the flat nearly on edge and gently pull back on the plants in one corner to reveal the roots. Roots should be occupying most of the media but not be root-bound and circling in the flat. Lift bare-root material and shake off the sawdust or other holding material to expose the roots.

When plants are removed from the container or otherwise inspected, the roots should be fibrous and of sufficient density to hold the soil and root mass together. Roots enclosing the outside of the root ball should be small to medium sized and not too densely entwined or matted. Main roots should be free of kinks and circles; all roots should be free of disease, insects, and nematodes.

Not all kinked and circling roots are necessarily harmful. Only main roots with more than a 90° turn and 80% of the root system below the kink and at the surface or center, or those that circle 80% or more of the root system by at least 360°, generally cause problems. If necessary, remove or wash away some of the potting soil at the center around the trunk-surface area to examine the roots.

Circling roots on the outside of the root ball are fairly common, especially in container-grown plants, are usually not a problem, and can be corrected at planting. The root system is probably not abnormally pot-bound if plant tops are healthy and vigorous.

Generally, healthy root tips are white or light colored. Sometimes roots have a dark outer portion and are firm and lighter colored inside. These roots are healthy, too. Diseased or rotten roots are usually soft, dark, and mushy, and when pulled, the outer portion strips away easily, leaving a slender, threadlike core.

Although plants are generally sold by container size, there is not necessarily a relationship between the size of plants and their containers. If inspection of the root mass reveals few roots on the outside, one is probably paying for a larger plant than one receives.

Plant Health

Plant health is characterized by vigor (a measure of a plant's ability to do well once planted) and freedom from injury and pests. Indicators of vigor include green to dark green color, relatively large leaves and dense foliage, smooth bright bark, and adequate shoot growth. Evaluation of plant vigor is relatively subjective and requires a good knowledge of a species when making such assessments, because many of the indicators vary from species to species. Obviously, plants should be free in all their parts from injury, disease, and pests.

Planting

Once you have selected a healthy, vigorous, well-grown plant of the appropriate species for the right place in the landscape, the next step is to plant it properly. The performance of landscape plant material depends a great deal on how it is planted. Although container-grown and flat-grown plants can be planted any time of year in areas that do not experience extended subfreezing weather, the spring and fall months are usually the best times to transplant trees, shrubs, and ground covers. Weather conditions during these periods are typically moderate, enabling plants to avoid heat or cold stress while they are establishing new root systems. Summer planting can also be successful, but it requires more careful irrigation management to ensure root balls do not dry out or become saturated for extended periods.

Digging the Hole

Plant the tree, shrub, or vine so that the top of the root ball is at the same grade as the surrounding soil (fig. 12.1). Dig the hole

the same depth as that of the root ball. Planting more deeply or in loose soil that can settle with time, causing the plant to be deeper than intended, may lead to future problems such as crown rot.

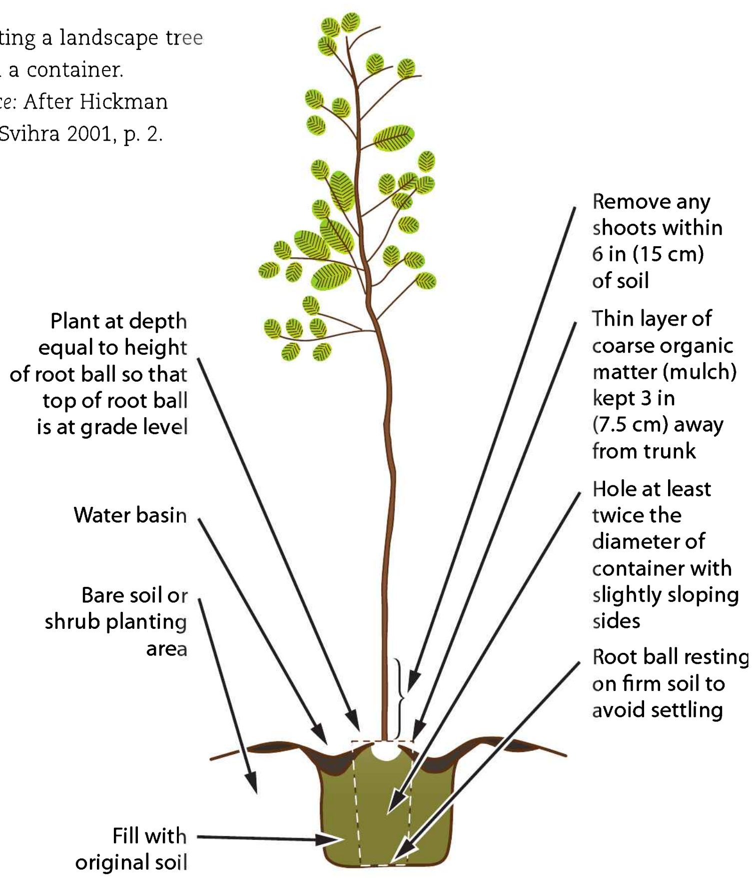
The width of the hole should be a minimum of twice the diameter of the container or root ball. The wider the hole, the faster the roots will grow out of the root ball and into surrounding soil. For bare-root plants, spread the roots out evenly without bending or crowding them. If planting in compacted soil, it may be necessary to dig deeper to break up impervious zones or layers. If so, wait 2 to 4 weeks before planting to give the loosened soil the chance to settle.

Backfill

Place the plant's root ball so that it rests firmly on the undug bottom of the hole. Backfill around the root ball with unamended soil dug from the hole, being sure to water the soil thoroughly to remove air pockets. Recent studies have shown that nothing is gained by amending the backfill with organic matter, fertilizer, vitamin B_1, or other substances. In fact, the practice could be harmful. It is much better and more efficient to use organic matter as a mulch spread over the soil after planting to improve soil structure, conserve water, and discourage weeds. Using the remaining soil dug from the hole, construct a water basin that is initially the same diameter as the root ball. Gradually widen the basin as the plant becomes established. Remove it completely after the first growing season.

Figure 12.1

Planting a landscape tree from a container.
Source: After Hickman and Svihra 2001, p. 2.



Mulching and Irrigation

After planting, add a layer of coarse organic material as a mulch 2 to 3 inches deep and irrigate thoroughly (flood the basin) to settle the soil. Keep the mulch 3 to 6 inches away from the trunk. Judicious water management is critical for newly planted landscape material. The original root ball must not be allowed to become completely dry for any extended period during the establishment of a woody plant. Remember that, although the new plant may be large, its root volume still occupies a rather limited area. Root balls of plants that were oversized in their container or slightly pot-bound can dry out more quickly than the surrounding backfilled soil. Until the roots grow out and become established in the parent soil, frequent but light watering may be needed. As the plant becomes established, irrigations can become less frequent but deeper.

Plants Grown in Flats

When transplanting plants grown in flats, cut or tear away the rooting media around each plant to form individual well-rooted transplants. Water the flats thoroughly at least several minutes before attempting to remove plants. Plants available in flats are typically intended for mass planting in beds or similar groupings; transplants are

usually spaced 12 to 18 inches apart so that they completely cover the soil within about one growing season. The planting area should be weed-free and the soil slightly moist at the time of planting. It is not necessary to completely till the bed before planting, but the soil must be loose enough to easily dig small planting holes with a trowel or similar tool.

Dig the planting holes one and a half to two times wider than and at the same depth as the root ball of each plant removed from the flat. Set the plant in the hole and gently backfill around the root ball with soil dug out. Do not pack the backfill and do not bury the root ball under a thick layer of soil.

Water the planting thoroughly immediately after planting to settle the soil around the root ball and ensure that there is adequate moisture available to the transplants. It may require ½ inch of water or more to achieve this. Check soil moisture and the moisture in root balls frequently. Irrigate as frequently as necessary to keep the root balls moist (but not saturated) for a month or so after transplanting if rainfall does not occur. It may be necessary to water lightly every day in warm weather. As new roots grow into the native soil and plants begin to establish, irrigation should be less frequent but heavier at each watering.

Preplant fertilizer is not recommended. Apply fertilizer according to the recommendations in table 12.2 shortly after transplanting and follow with a regularly scheduled irrigation if rainfall is not imminent. Keep the planting free of weeds by hand-weeding, cultivating, or applying a preemergent herbicide labeled for the species in the planting. In plantings where the plants do not spread via runners that root along the soil, a thin layer of organic mulch can be applied to aid weed control and soil water management.

Plants in Lawns

If plants are installed in turf areas, keep the grass well away from the trunk of the new plant for 2 to 4 years to reduce competition from the grass for water and nutrients. Keeping the ground free of other plant growth at least 12 inches in all directions from the trunk also prevents damage from mowers, edgers, and weeders. Using plastic guards to prevent this type of mechanical damage may be useful, because such damage can kill or severely dwarf young plants.

Staking

Trees should be staked for support, protection, or anchorage when needed. With few exceptions, there is little need to stake trees for trunk support if they were grown properly with adequate space in the nursery. However, many nurseries stake trees for ease of handling and to maximize space; thus, they may be staked for about one growing season when planted in the landscape. Trees with large tops in proportion to their roots may be staked. Even these trees can often stand alone, however, without staking by simply thinning out about a third of the branches to lighten the crown and reduce its wind resistance.

Table 12.2.

NITROGEN FERTILIZATION RECOMMENDATIONS FOR NEWLY PLANTED TREES, SHRUBS, VINES, AND GROUND COVERS

Plant material	Nitrogen rate per application	Application frequency and timing
newly planted tree, shrub, vine	0.2 1b N in 3 ft × 3 ft area around base of plant	Immediately after planting, 6–8 weeks after planting, and the following spring
newly planted ground cover	1 to 2 lb N per 1,000 sq ft	Immediately after planting and again 6–8 weeks after planting

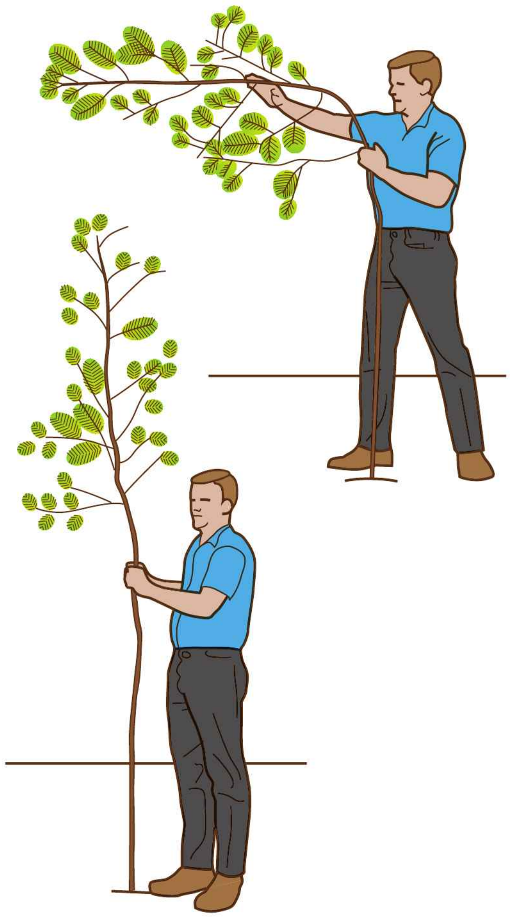


Figure 12.2

Stakes should be no higher than necessary to hold the tree upright, while allowing the top freedom to move in the wind. To find the correct height, grasp the trunk with one hand and bend the top. If the top returns to its upright position when released, tie the trunk to stakes at the height of the bend. *Source:* After Harris et al. 1978, p. 6.

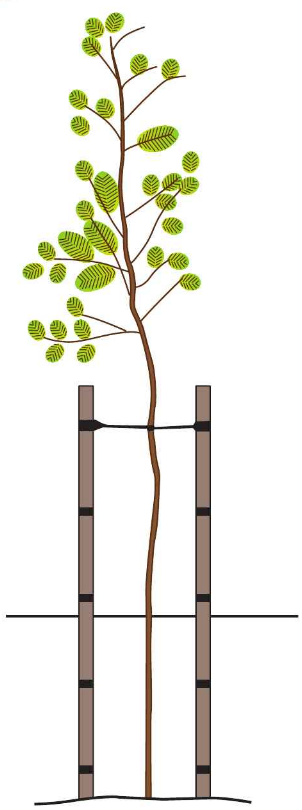


Figure 12.3

Tie tree to stakes at the correct height using flexible webbing material. *Source:* After Harris et al. 1978, p. 9.

If newly planted trees will not stand upright without support or if frequent, heavy winds are a problem, staking may be necessary. Staking to support a tree should be as low as possible on the trunk but still high enough that the tree will return to an upright position after being deflected. To determine the proper point at which to stake and tie a tree, hold the trunk in one hand, pull the top to one side, and release. Attach the ties at the height at which the trunk will return to upright when the top is released (figs. 12.2–12.3).

Use two support stakes, one each on opposite sides of the trunk, positioning them so that a line drawn between them would be at right angles to the most troublesome wind direction. Make the stakes as short as possible but high enough to hold the tree upright under calm conditions. The tree should return to vertical after the wind has bent the top. Loosely tie the trunk to each stake at just one level, at the point near the top determined by the technique shown in figure 12.2. This technique allows the trunk below the tie to bend in the opposite direction from the top during a wind. Material used for ties should have a broad surface to minimize rubbing or girdling and have some elasticity to provide greater flexibility as well as support. Each tie should form a loose loop around the trunk, one right above the other, and the two together should provide the necessary support at the right place (see fig. 12.3). Cut both stakes just above where the last tie is placed to prevent the trunk from being damaged by rubbing or hitting the stake above the tie.

Provide flexible movement at the tying point without allowing the tree to contact the stakes. Trees whose trunks and tops are allowed to flex, give, and move a little develop greater trunk caliper and taper, stronger wood, a larger root system, and less wind resistance, because the top is free to bend. They become self-supporting at an earlier age than trees that are rigidly staked.

As the tree grows and becomes better

established, remove or lower ties and shorten the stakes so that they do not rub against the trunk and cause rubbing or girdling injury. Ties can probably be removed by the end of the second growing season. Use stakes for the shortest possible time.

To provide extra protection from lawn mowers and other mechanical damage, drive three stakes that are 2 inches by 2 inches thick and about 3 feet long at equidistant positions around the root ball. Drive the stakes into the undisturbed soil until about 12 inches remains above ground level.

Even on newly planted trees whose trunks do not need support, trunk movement could break new roots growing out of the root ball into the parent soil if the root system is not well anchored. Two or three short stakes placed as suggested above provide protection from mechanical damage and enough anchorage for the roots. Ties from each of the stakes to the trunk will usually be sufficient to keep the roots firmly in the ground. The top may need thinning to decrease wind resistance and weight. Ties can be removed after the first growing season and the stakes left for trunk protection.

Pruning

If the right plant species is selected for the right spot and purpose in the landscape, it is usually unnecessary to prune mature, well-established trees and shrubs. When done improperly, pruning can be one of the most destructive horticultural practices, destroying the shape and structure of a tree and predisposing it to severe problems in the future. Topping mature trees (heading back the main leader) is not usually recommended because it seriously injures trees, disfigures them, and forces the growth of many vigorous upright shoots that are weakly attached. When proper techniques are used, however, judicious pruning of woody plants serves several useful functions. Pruning can train young plants, groom for appearance, control shape and size, influence flowering and fruiting, invigorate stagnant growth, and remove damaged or pest-infested growth. Consider hiring an International Society of Arboriculture (ISA) Certified Arborist to assess and prune large trees.

Types of Pruning Cuts

The two main types of pruning cuts are head (heading back) and thin (thinning out); a woody plant responds differently to each type of cut. Heading back is cutting the plant back to a stub, lateral bud, or small lateral branch (fig. 12.4). Depending on the severity of pruning, heading back results in a flush of vigorous, upright, and dense new growth from just below the cut. New shoots formed on older, larger limbs are weakly attached and split out easily (figs. 12.5–12.6). Thinning (fig. 12.7) is removing a lateral branch at its origin or

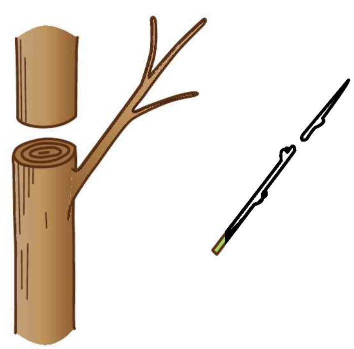


Figure 12.4

Heading back is cutting to a stub, small lateral, or bud. *Source:* After Harris et al. 1981, p. 3.

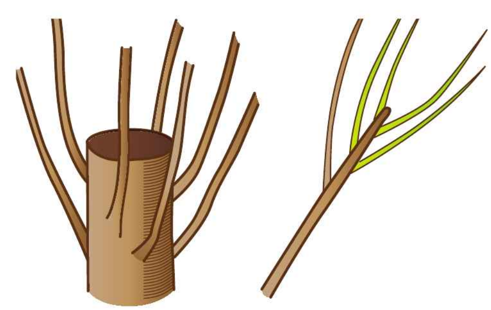


Figure 12.5

Vigorous upright growth stimulated by heading. *Source:* After Harris et al. 1981, p. 4.

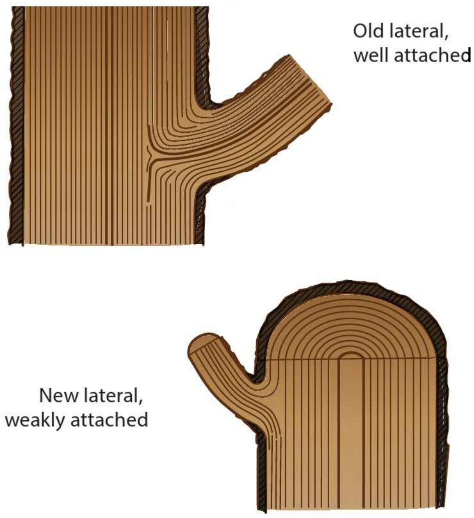


Figure 12.6

New shoots forced on older limbs are weakly attached and split out easily. *Source:* After Harris et al. 1981, p. 4.

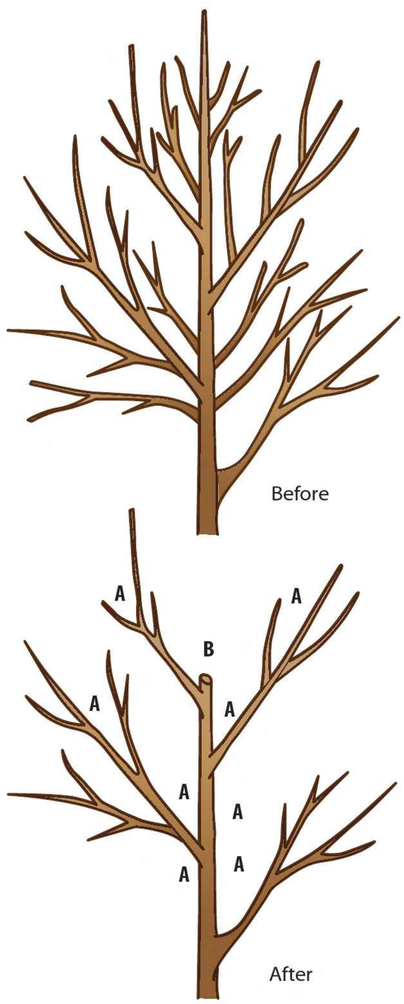


Figure 12.7

Thinning removes a branch (A) or cuts to a larger one (B). *Source:* After Harris et al. 1981, p. 4.

shortening a branch's length by cutting to a lateral large enough to assume the terminal role. A woody plant responds to thinning by becoming more open but retaining its natural growth habit and does not usually produce a flush of new vigorous growth from the cut. Foliage grows more deeply into the tree because more light can penetrate the canopy.

Making the Cut

Pruning shears (or loppers) are used for cutting small limbs, and saws are used for large ones. If diseased plants are pruned, disinfect pruning equipment after each cut to prevent spreading disease with denatured rubbing alcohol or a chlorine bleach solution. When pruning trees and shrubs that have been grafted, remove new shoots that start below the graft union, but be careful not to remove all of the stems that start above the graft union. Small limbs, including suckers and water sprouts, should be cut close to the trunk or branch from which they arise. Cuts are made most easily with a single, upward cut of the blade. On most kinds of trees, new shoots will be less likely to grow from remaining latent buds if small limbs are cut closely.

When heading back trees or shrubs, cut small stems back to about ¼ inch from a lateral bud or branch. Make the cut on a slight slant away from the bud or branch. New growth will usually grow in the direction the bud or branch points (figs. 12.8–12.9).

Large tree limbs must be cut with a saw. The recommended procedure is to remove a limb in two steps involving three cuts (fig. 12.10). Make the first cut on the underside of the branch 1 to 2 feet from the crotch and at least one-third of the diameter deep. Make the second cut downward, 1 to 3 inches farther from the crotch than the first. The limb should then split cleanly between the two cuts without tearing the bark. Make a third cut to remove the remaining stub just outside the crotch; this position is

Figure 12.8

Make pruning cuts about ¼ inch above a bud and slightly angled away. *Source:* After Caldwell et al. 1972, p. 10.

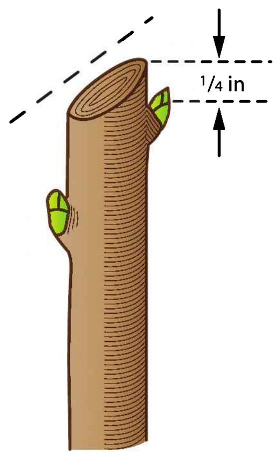


Figure 12.9

Prune back horizontal limbs (A) to a more upright lateral or (B) to an upward-growing bud. *Source:* After Harris et al. 1981, p. 18.

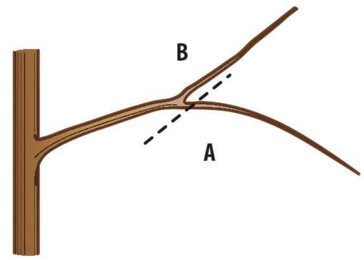
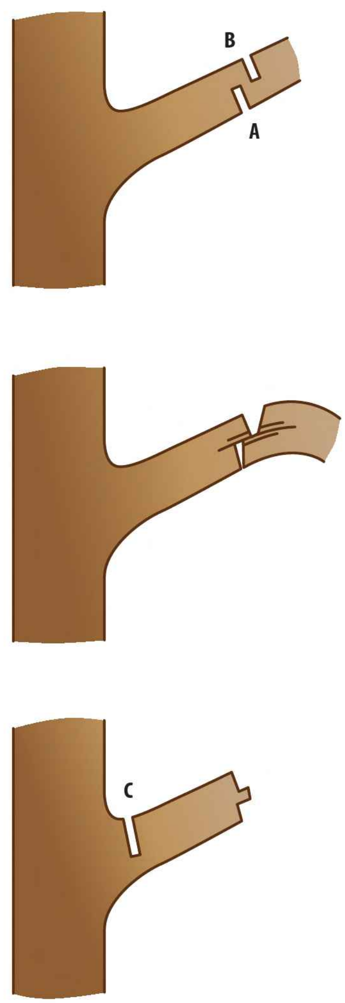


Figure 12.10

To remove a large limb, make the first cut at (A), second at (B), and third at branch bark ridge (C). *Source:* After Harris et al. 1981, p. 5.



required to ensure rapid closure of the wound. Most trees form ridges, called branch bark ridges or shoulder rings, on the top and bottom of branches where they are attached to the trunk. The third cut should be made just outside the branch bark ridge (fig. 12.11). The cut should not be flush or parallel to the trunk but out from it slightly, with the lower edge of the cut farther away from the trunk than the top one. Such a cut will form a smaller wound than a flush cut and will close more quickly.

Protecting pruning cuts with an asphalt emulsion or other coating material is of no value and could even be harmful to the tree. Coatings and coverings can trap moisture and increase the chances of decay and retard wound closure. The best practice is simply to let the wound dry in the air. Paint a mixture of one-half water and one-half interior white latex paint on the southwestern portions of the newly exposed trunk and branches after pruning to help prevent bark injury from sunscald on thin-barked tree species in which this is a concern.

Pruning Trees at Planting

Landscape trees should not be pruned at planting time except to remove damaged branches or to correct those that show serious structural problems, such as

branches with extremely narrow crotch angles and branches that cross or rub other branches. In the past, it was commonly recommended to prune a portion of the shoots at planting. Recent research, however, has shown that the removal of terminal buds and leaf area can delay and reduce root system growth. Because the survival and establishment of a transplanted tree depend greatly on the growth and development of new roots, the practice of pruning at transplanting is no longer standard.

There is one exception, however. If irrigation is unavailable after planting, or if severe drought is anticipated after planting, limited thinning-type pruning may help the tree to survive. Although this pruning may restrict root growth, thinning cuts remove foliage and thereby reduce transpiration and water loss.

Figure 12.11

Pruning cuts should be made just outside the branch bark ridge (top of cut) and the collar (bottom of cut) so that the bottom of the cut is angled slightly outward. *Source:* After International Society of Arboriculture 1995, p. 3.

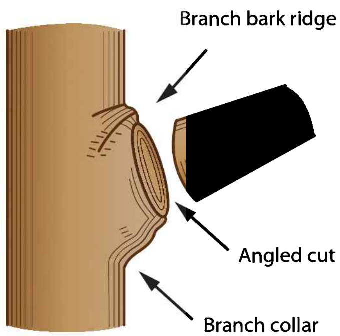
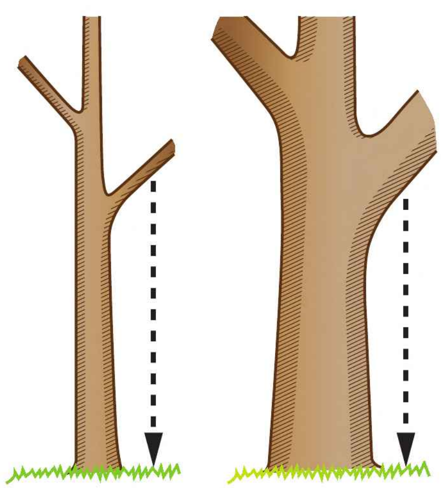


Figure 12.12

Branches retain their position on the trunk but become slightly closer to the ground as they increase in diameter. *Source:* After Harris et al. 1981, p. 11.



Pruning to Train Young Trees

Directing the growth of young trees is important if the trees are to perform properly in the landscape when mature. The growth habit of a plant and its landscape use largely determine the extent to which a tree must be trained to obtain the desired form. Pruning is usually the most effective way to direct the growth habit of a plant. Young trees with a strong central leader, like conifers and sweetgum, may need little or no pruning. Other tree species, such as Chinese pistache and some flowering fruit trees, lack a strong central leader, have more irregular growth, and need a higher degree of training. Street trees should have higher scaffold branches than trees used for visual screening or windbreaks.

Prune a tree only enough to direct its growth effectively and correct any structural weaknesses. The height of the first permanent branch above the ground depends on the tree's intended landscape use. The lowest scaffolds on trees in lawn and garden areas are normally no higher than 6 to 8 feet from the ground. Those on trees along streets and sidewalks should be 8 feet above a sidewalk and 8 to 10 feet above the street. The position of a limb on a trunk remains essentially the same throughout the life of the tree (fig. 12.12). Branches selected for permanent scaffolds should have wide angles of attachment, be smaller in diameter than the trunk, and be spaced 18 to 24 inches apart vertically (fig. 12.13).

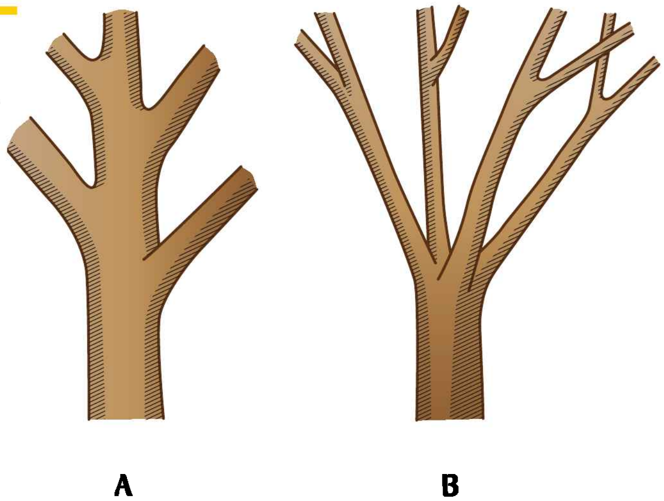


Figure 12.13

Well-spaced branches (A) are less likely to split or break than those close together (B). *Source:* After Harris et al. 1981.

Radial branch distribution should allow five to seven scaffolds to fill the circle of space around the trunk.

As a tree ages, the trunk grows over and around wide-angled branches, which makes their attachment very strong. Narrow crotch angles and closely spaced branches arising near the same junction create weak branch attachments. These branches have narrow points of attachment and usually develop a bark inclusion at the junction with the trunk that further weakens their attachment as the tree grows. Such branches are likely to eventually split off at the junction.

Many trees produce an abundance of lateral growth. Direct this growth during the growing season by heading back or thinning out shoots competing with the leader or interfering with those selected for scaffold branches. During the first and perhaps the second season, leave more shoots unpruned than will finally be selected for scaffolds, allowing more choices later for selection of the best lateral branches. Often, on lightly or unpruned trees, the more vigorous branches will be naturally well spaced, and other branches will become rather weak.

If a tree seems reluctant to develop laterals for future scaffolds, pinch out (head back 1–2 in) the tip during the growing season when the growing point reaches a height at which a lateral branch is desired (fig. 12.14). Select the most vigorously growing new shoot that developed from the buds below the pinch as the new leader. Then choose as a lateral a second developing shoot growing in the desired direction by pinching the tips of the other shoots that were formed. Repeat this process as the leader develops until the desired number and spacing of laterals are obtained. A vigorously growing tree may permit forcing as many as three well-spaced laterals where they are wanted in one season.

Pinching during the growing season is much more effective, requires removing a much smaller quantity of shoot material, and results in less dwarfing of the plant than does dormant pruning. A growing-season pinch of only 1 to 2 inches is just as effective and will make unnecessary the removal of a large branch later during the dormant season. Without pinching during the growing season, the leader would require severe heading to the height at which the lowest lateral is desired during the dormant season.

Pruning Mature Trees

Once well-spaced scaffold branches and the main structure of a tree have been created, usually by the third or fourth year, the tree will probably need little or no pruning for several years, especially if it is the right tree for the right place and purpose. Mature trees, however, must be pruned for health and appearance, size control, and flowering and fruiting response. Pruning the leader of a central leader tree and wholesale topping (heading back) of mature trees are inappropriate. These practices destroy a tree's natural form, create large wounds, and force many vigorous upright shoots that are weakly attached (figs. 12.6, 12.15).

Removal of dead, weak, diseased, and insect-infested limbs improves tree health

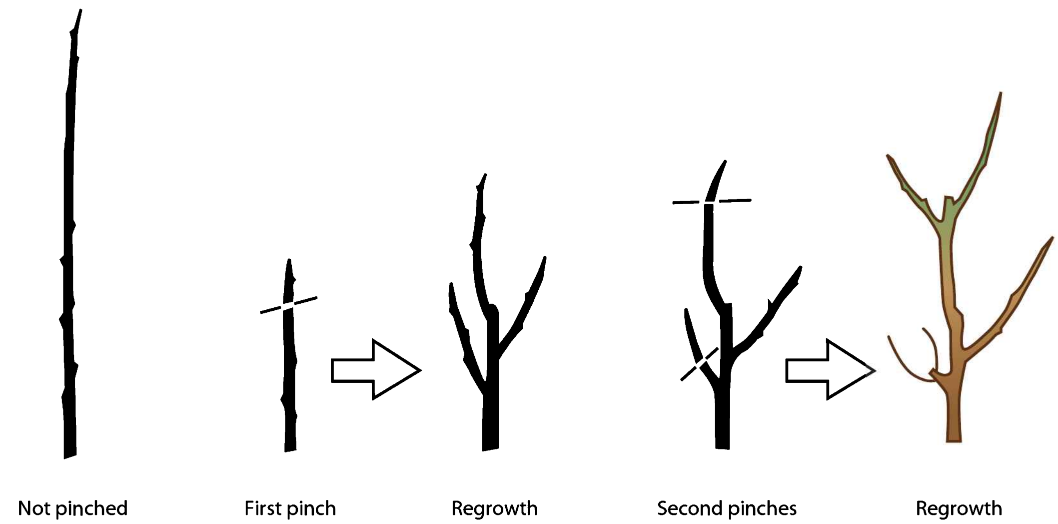


Figure 12.14

During the growing season, a nonbranching leader can be pinched to induce development of laterals. The two pinches induce branches to grow at the heights desired (leaves removed). *Source:* After Harris et al. 1981, p. 14.

and appearance. Remove low, broken, and crossing limbs for appearance and safety. Open up the top of the tree to let in more light so that interior leaves and branches can remain healthy. Judicious pruning consisting of moderate thinning can open a tree to view and emphasize an attractive or picturesque feature to the viewer.

Although pruning for size control is less preferred than proper species selection, it may be necessary in some instances. If trees were planted too closely together or if the particular function or purpose for which a tree was originally selected has changed, size control through pruning could be the best alternative to removal or replanting.

Thinning, perhaps even the complete removal of some limbs, can reduce the height and spread of a tree. A thinned tree retains its natural shape and is less prone to the formation of vigorous water sprouts than a headed tree (fig. 12.16). Pruning for size control, however, is most effective as soon as a tree reaches the desired size. Delaying pruning until the tree is larger makes pruning more difficult and less effective, leaves more noticeable scars, and encourages excessive growth. Heading and stubbing, while much more rapid and drastic in their effect, are in most cases much less desirable.

Severe pruning delays the onset of flowering in species that flower on 1-year-old growth, such as the flowering fruit trees. Once the tree has begun flowering, only a light annual thinning to remove 10 to 15% of the leaf area and to reduce crowding or weak branches is usually necessary. Perform such thinning at or near

Figure 12.15

A headed tree will force many vigorous upright shoots, causing the tree to lose its natural form. *Source:* After Harris et al. 1981, p. 22.

the end of the bloom period to encourage vigorous growth on which to bear next year's bloom.

On the other hand, trees flowering on current year's growth, such as crape myrtle, Japanese pagoda tree, and jacaranda, usually flower earlier and more profusely if pruned to stimulate and maintain vigorous growth. Plants with such flowering habits should be pruned more severely during the winter before growth begins.

Pruning Conifers and Other Narrowleaf Evergreens

Although conifers usually require less pruning than broadleaf trees, the same basic principles apply for controlling size, creating special effects, and shaping. The crown configuration cannot be controlled as easily as with broadleaf trees. Dead, diseased, crowded, and structurally unsound branches should be removed first. Double leaders should be thinned to one unless the natural growth habit includes several main branches. Encourage branches with wide angles of attachment and smaller than the trunk from which they arise.

Pruning conifers differs from pruning broadleaf trees in several important ways. Conifers usually do not need pruning for spacing of laterals. Several branches arising at or near one level on the trunk seldom subdue the main leader of a conifer; thus, whorls of branches or those arising close together can remain, because it is unlikely they will crowd out the leader. Adequate vertical spacing between individual branches along the trunk occurs naturally in most conifers. The branches may be thinned to reduce wind resistance or to achieve aesthetic effects. For a strong, well-tapered trunk, branch whorls or laterals remain along the trunk.

Growth habit determines the severity of pruning. Conifers with a tall, straight trunk and central leaders are said to have excurrent growth. Almost all conifers are excurrent when young. Conifers are usually most attractive if the excurrent habit is preserved. Thus, the primary pruning removes or subdues any laterals that challenge the leader. Other conifers, like many mature broadleaf trees, develop a wide-spreading crown after forming a short trunk and are said to have a diffuse, random branching habit. Some conifers may develop the diffuse branching habit if they have been propagated by cuttings from side branches. The diffuse branching pattern allows more latitude in pruning.

The distribution of latent buds or growing points often limits the severity of pruning conifers (table 12.3). In some conifers, all growth derives from buds formed in the previous growing season. When the preformed buds have expanded, growth ceases. These trees may have all their lateral buds in whorls just below the terminal bud, or lateral buds may be scattered along the shoot. Conifers with whorled buds should be pruned back only to active laterals or, in current season's growth, before the needles develop fully. If pruning is done

Figure 12.16

Thinning reduces height and opens up a mature tree (A), retaining the natural appearance and form of the tree (B). *Source:* After Harris et al. 1981, p. 22.

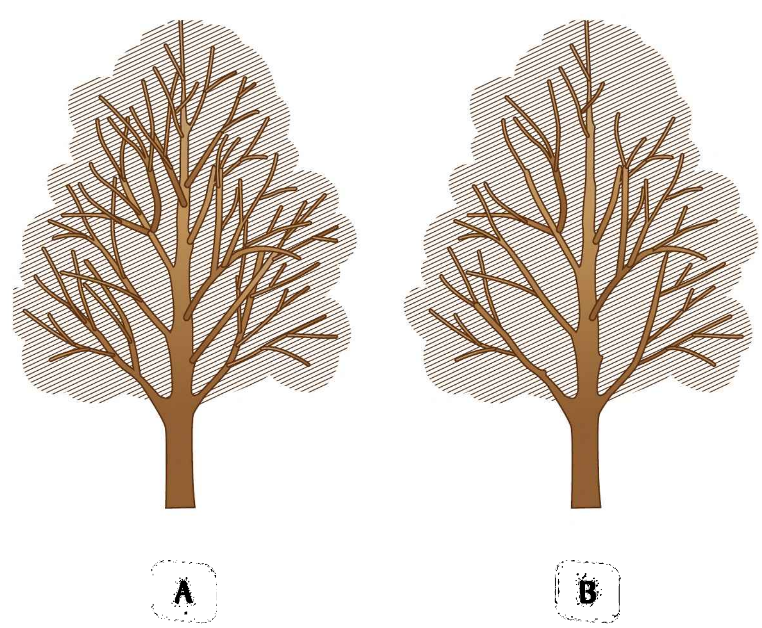


Table 12.3.

PRUNING GUIDELINES FOR CONIFERS

Plant	Branch pattern	Latent buds on old wood	Type of growth	Method of pruning for given response: Reduce size, direct growth	Method of pruning for given response: Increase density	Method of pruning for given response: Slow growth (dwarf)	Comments
Abies spp.	whorled	no	All new growth from preformed buds.	Thin branch back to laterally growing shoot. Do not cut behind last remaining needles.	Remove apex of laterals only; do not pinch leader.	Root-prune; prune late in summer.	Pruning not needed except to remove dead and diseased wood.
Juniperus spp.	random	some	Growth continues as long as conditions are favorable.	Thin branch back to laterally growing shoot.	Can be sheared or clipped, and some can be headed to old wood.	Root-prune; prune late in summer.	
Picea spp.	whorled	no	All new growth from preformed buds.	Thin branch back to laterally growing shoot. Do not cut behind last remaining needles.	In spring, clip new shoots one-half their length when needles are one-half expanded.	Root-prune; prune late in summer.	Pruning not needed except to remove dead and diseased wood.
Pinus spp. (most but not all)	whorled	no	All new growth from preformed buds.	Thin branch back to laterally growing shoot. Do not cut behind last remaining needles.	Pinch candle when expanding in spring. Branching is induced between existing whorls by girdling trunk between whorls.	Root-prune; prune late in summer.	
Pinus canariensis	whorled	yes	Often makes single flush of growth, but growth can continue under favorable conditions.	Thin branch back to laterally growing shoot.	Pinch candle when expanding in spring. Branching is induced between existing whorls by girdling trunk between whorls. Laterals can be headed to desired length.	Root-prune; prune late in summer.	
Podocarpus spp.	random	no	Growth continues as long as conditions are favorable.	Thin branch back to laterally growing shoot. Do not cut behind last remaining needles.	Can be sheared, but form is retained by removing only apex of each shoot.	Prune late in summer.	
Pseudotsuga spp.	whorled	no	All new growth from preformed buds.	Thin branch back to laterally growing shoot. Do not cut behind last remaining needles.	In spring, clip new shoots one-half their length when needles are one-half expanded.	Prune late in summer.	
Sequoia spp.	random	yes	Growth continues as long as conditions are favorable.	Thin branch back to laterally growing shoot.	Can be sheared, but form is retained by removing only apex of each shoot. Can be headed back into old wood.		
Taxus spp.	random	yes	Growth continues as long as conditions are favorable.	Thin branch back to laterally growing shoot.	Can be sheared, but form is retained by removing only apex of each shoot. Can be headed back into old wood.	Prune late in summer.	Foliage of some is poisonous. Dispose of clippings safely.
Thuja, *Chamaecyparis*, *Cupressus*, and *Calocedrus* spp.	random	no	Growth continues as long as conditions are favorable.	Thin branch back to laterally growing shoot. Do not cut below foliage.	Can be sheared or clipped.	Prune late in summer.	

Source: Adapted from Harris et al. 1981, p. 27.

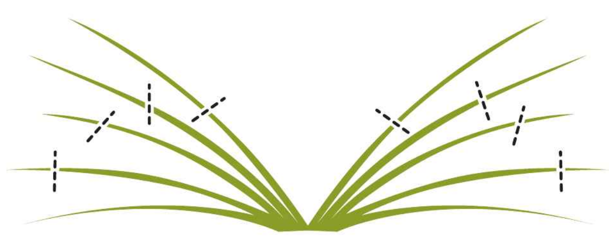
early enough, new buds will develop near the cut for the following season's growth. In conifers with latent buds scattered along the younger shoots, prune back to a latent bud. These buds will become active and develop a new growing point. Canary Island pine *(Pinus canariensis)* is a notable exception. Many latent buds survive just under the bark on large branches and even the trunk. Many of these buds grow when stimulated by heavy pruning into old wood or after a fire has killed the smaller branches.

If conditions are favorable, some conifers with preformed buds, including some pines, may have several growth flushes during a growing season. Young, expanding shoots may be pruned in any or all of these flushes. If there are no visible latent buds, pruning into old wood will usually result in a stub from which no new growth will arise.

Other conifer species have buds or dormant growing points (no bud scales formed) with shoots that continue to elongate. Such species usually have abundant latent buds that produce new growth even when severely pruned into old wood. Trees of these species usually have a spiral or random branching habit. Despite their tolerance of severe pruning, these species look most attractive when thinned. Conifers with an intermediate growth habit have a large number of latent buds randomly spaced along stems or retain active laterals or short shoots for many years on older wood. Growth continues as a series of flushes.

Figure 12.17

Spreading-type narrowleaf evergreens. Prune spreaders by cutting back longer upper branches as shown. Long branches should be cut back from a few inches to half the branch, as shown, to prevent shading of lower branches. *Source:* After Caldwell et al. 1972, p. 11.



Pruning spreading-type narrowleaf evergreens

Plants such as junipers have a spreading growth habit. Prune junipers by cutting back enough growth to prevent leggy or uninhibited growth and to prevent needles from dropping off lower branches because of shading by upper branches. Cut back the longer branches that develop on top from a few inches to half the branch so the lower branches will be exposed to light (fig. 12.17). Cut back some growth annually to prevent plants from becoming too large. Pfitzer juniper is an example of a vigorous, spreading narrowleaf evergreen that can produce 12 to 18 inches of growth annually. It may be necessary to cut back into the previous year's wood to maintain the desired size and shape of the plant.

Pruning rounded-type narrowleaf evergreens

Brown yew and globe arborvitae are good examples of rounded-type evergreens. They are normally globe shaped and should not be sheared. Both can be maintained at whatever height and size desired. Because brown yew develops as a broad, rounded tree, prune about one-fourth to one-half of the previous year's growth to keep it bushy and compact. Thinning individual branches, rather than shearing, yields a more attractive, natural-looking growth habit. Globe arborvitae requires little, if any, pruning because of its formal growth habit.

Pruning Hedges

Hedges should be pruned back to the point of the last cut. The tops of hedges should be slightly narrower than the bottoms to ensure that adequate light reaches lower leaves to maintain density (fig. 12.18).

Pruning Broadleaf Shrubs

Prune shrubs to keep their natural shape unless they are used as formal hedges. Shearing (heading cuts) should not be widely used; thinning of older, taller growth should be the primary type of pruning. Cut off the largest, oldest branches at or very near the ground and leave the younger, shorter stem (fig. 12.19).

Figure 12.18

Prune hedge so that the base is broader than the top. Regular pruning is needed. *Source:* After Caldwell et al. 1972, p. 13.

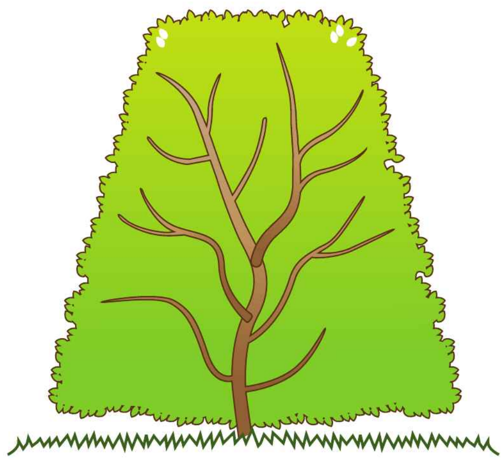
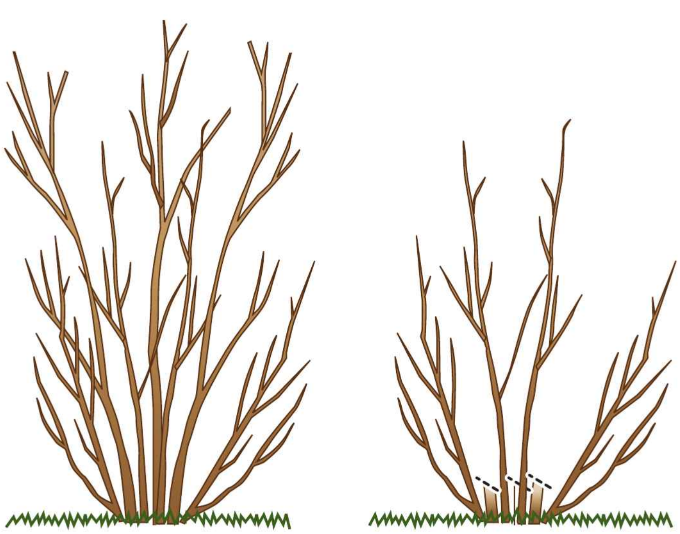


Figure 12.19

Prune broadleaf shrubs to keep their natural shape by using mostly thinning cuts. Avoid making heading cuts or shearing the whole plant.



These may be headed back if they are very weak or very sparse. New shoots that develop can be thinned and headed as needed to reshape the plant. For extremely large, overgrown plants that must be rejuvenated, it is best to cut out all old growth near the ground over a 2- to 3-year period so as not to destroy the plant's natural shape or flowering habit. Judicious thinning and selective heading of new shoots and young stems can then shape and control growth until rejuvenation is required again. Rejuvenated plants may not bloom for a year or more, depending on their growth rate and flowering habit.

Pruning Ground Covers

Pruning ground covers is usually necessary only to remove unhealthy tissue, awkward or straggling branches, or to keep a plant from becoming too large or invasive. Many ground covers are prone to decline as they age, however. Others are so vigorous that controlling their growth is an ongoing maintenance task. Periodic mowing is one way you can keep ground covers vigorous, neat, and healthy with no significant loss of attractiveness. Mowing is a convenient way to check rampant growth, thin out excessive stem buildup, and rejuvenate old, declining ground covers. Mowing also helps minimize problems with trash, vermin, fire, and sprinkler interference.

Suitable ground covers

Not all ground covers are suitable for mowing. Less vigorous varieties recover slowly, leaving an unsightly area prone to weed infestation for up to a year. Species with recovery times as long as 4 months still can gain in overall quality from mowing, however. Vigorous species, which usually recover within 1 or 2 months, respond well to mowing. Mowing can check their growth without harming visual appeal for an extended period. For example, in recent field studies at the University of California, mowing kept the growth of lantana in check yet had a negligible effect on overall quality. Other species, such as African daisy and coyote bush, responded

similarly. Varieties with herbaceous or nonfibrous stems are also good candidates for mowing because it is easy to cut and bag their stems.

Timing of mowing

Mow ground covers at the correct time (table 12.4) to ensure quick recovery with little weed invasion or loss of aesthetic value. Mow spring-flowering species after they have finished blooming. Mowing too early reduces or delays flowering. Spring mowing is appropriate for varieties that flower in summer or fall and those that do not produce flowers, such as English ivy. Vigorous ground covers may require multiple mowings each year to keep them in good appearance and at the desired size. Avoid fall mowing because the tender regrowth may be susceptible to early frost damage, and regrowth can be slow allowing weeds to invade the planting.

If ground covers develop heavy, succulent, or woody stems, they may become too difficult to mow. Mowing chops up the fleshy growth of succulent species, such as ice plant, making it impossible to collect and remove the cut debris. Large stems of woody species can clog or jam a mower. To achieve acceptable results, start mowing ground covers when they are young—just after establishment—and continue mowing regularly thereafter.

Mowing techniques

Use a string trimmer or an ordinary rotary turf mower set at the highest cutting height for ground covers with thin, nonfibrous stems and little thatch buildup, such as trailing lantana and garden verbena. Use a flail mower on ground covers with thick, woody stems or heavy thatch buildup. Though flail mowers are relatively cumbersome, they may be necessary for the initial cut. A string trimmer or rotary mower should be adequate for subsequent mowings, if you perform them regularly.

Mow ground covers at or slightly above the branching points on stems—in most cases, 4 to 6 inches high. Although you usually cannot set mowers this high, a rotary turf mower tends to ride up on top of the ground cover as you mow. Thus, if you set the mower at its maximum cutting height, the cut should be acceptable. Mowing too low slows recovery, and mowing too high does not achieve the desired result. You may have to experiment to determine the best mowing height for a particular ground cover and condition.

Mow in the same pattern as an irregular turf area. Back-and-forth movement, keeping to the contours of the site, is best. Manually collect heavy clippings if the ground cover is so dense that the clippings remain on top as unsightly debris. Otherwise, let the clippings fall into the ground cover, where they will decompose, or collect them in the mower bag as you would when mowing turf.

For rapid recovery and to ensure good ground cover vigor, irrigate and fertilize with 1 to 2 pounds of nitrogen per 1,000 square feet after mowing.

Use a preemergent herbicide if recovery is slow and the ground cover is sparse. Check crop registrations and follow all label directions.

Delay postbloom mowing if a ground cover has a showy display of fruit.

Consider additional mowing to remove old, unsightly flower heads or objectionable seed or fruit, or if the ground cover regrows beyond the desired height. Set the mower height to remove seed or fruit but not vegetative growth.

Pruning Vines

Vines usually need pruning to limit growth, thin stems and branches, and remove dead or damaged wood. Some vines, such as honeysuckle, grow so fast and become so thick that considerable pruning may be necessary, but other vines need little pruning. Prune most vines in the dormant season, including the summer-flowering clematis (Jackmani type). The Florida and Patens types, including *Clematis montana*, blossom on 1-year-old wood and should be pruned by thinning out in spring before growth. Prune dead,

diseased, and damaged vines back to healthy wood. Interfering branches of woody vines, such as wisteria, should be cut back below the point of interference or all the way back to the junction with the main stem.

In general, prune out the top third of overgrown woody vines and prune by a third or more old, mature stems that are declining in vigor. Each year, prune stems of wisteria to promote new growth and flowers. Prune back plant tops to force out new branches. Pruning wisteria extensively during the dormant season may encourage rampant vegetative growth the next spring. Instead, prune out long, straggly growth in July, except branches needed for climbing. This technique is more likely to induce flowering. Shoots should be cut back to one-third to one-half of their length, which will induce production of short spurs on which next season's flower clusters will be borne.

Table 12.4.

MOWING TIMES FOR SELECTED GROUND COVERS

Scientific name	Common name	Mowing time*
Achillea tomentosa	woolly yarrow	spring
Ajuga reptans	carpet bugle	summer
Baccharis pilularis	coyote bush	spring
Ceanothus × 'Anchor Bay'	Anchor Bay ceanothus	summer
Ceanothus gloriosus	Point Reyes ceanothus	summer
Cotoneaster dammeri	bearberry cotoneaster	spring
Drosanthemum hispidum	pink ice plant	summer
Euonymus fortunei 'Colorata'	purple-leaved winter creeper	spring
Hedera helix	English ivy	spring
Hypericum calycinum	Aaron's beard, St. Johnswort	spring
Juniperus spp.	juniper (prostrate forms)	spring
Lantana montevidensis	trailing lantana	spring/summer
Lonicera japonica 'Halliana'	Hall's honeysuckle	spring
Mahonia repens	creeping mahonia	spring
Myoporum parvifolium	prostrate myoporum	summer
Osteospermum fruticosum	trailing African daisy	summer
Pachysandra terminalis	Japanese spurge	spring
Polygonum spp.	knotweed	spring
Potentilla tabernaemontanii	spring cinquefoil	spring
Rosa banksiae	Lady Banks' rose	spring
Rosa creeping varieties	Alba Meidiland, Fairy	spring
Sedum spurium	stonecrop	spring
Trachelospermum jasminoides	star jasmine	summer
Vinca major	periwinkle	summer

Note: *Additional mowing in other seasons may be needed to maintain plants at the desired size and height.

Timing for Pruning Trees

The time to prune depends on the kind of plant and the desired results. The following types of pruning can be done anytime: light pruning; pruning to remove unwanted small growth; and removal of damaged, weak, or diseased branches. Rapid growth can be maintained by pruning before the period of most rapid growth, usually in the spring. Prune deciduous trees during the dormant period and evergreen trees just before growth resumes in the spring.

Conversely, to retard plant growth, prune when growth is nearly complete for that season. For many plants, this time for maximum dwarfing is late spring to middle summer. Directing the growth of young trees is done best during the growing season.

Generally, spring-flowering plants should be pruned as soon as the flowers fade and new growth begins. Their flower buds form on growth produced during the previous year, so pruning these plants in the winter or just before they flower removes many of the flowers. Summer- and fall-flowering plants should be pruned in the winter or dormant season, because their flowers form on growth produced in the same growing season.

Fertilizing

Most mature trees, shrubs, and ground covers established in the landscape and growing in a healthy manner need little or no fertilization. In fact, fertilizing healthy trees can be detrimental by encouraging excessively vigorous growth that unnecessarily increases plant size and foliage density, produces succulent weak growth,

and predisposes the plant to diseases, pests, and environmental stresses. In addition, excessive fertilizer is a significant contributor to groundwater contamination of aquifers. Do not fertilize plants unless they need it.

In most cases, trees and shrubs growing poorly in the landscape do not need extra fertilizer since the causes of their poor growth are usually not nutritional. Fertilizers may be helpful but only after the problem(s) causing poor growth are corrected. Poorly growing plants may exhibit one or more of the following symptoms:

- light green or yellow leaves
- leaves with dead spots
- smaller leaves than normal
- fewer leaves or flowers than normal
- stunted twig growth or dieback
- wilting

Many problems may be responsible for these symptoms, including compaction, poor soil drainage or aeration, improper soil pH, diseases and pests, and adverse climatic conditions. Fertilizing will not remedy these problems.

In general, woody plants should not be fertilized at the time of planting, because fertilizer that is mixed with backfill or otherwise applied at this time may inadvertently injure roots. It is good insurance, however, to fertilize plants soon after planting. Fertilizing young, newly planted trees and other woody plants may promote more rapid growth so that the plants attain their optimal size more quickly. Fertilizing mature woody plants, vines, and ground covers is not routinely necessary unless plant vigor is low because of inadequate essential nutrients. As long as plants have good leaf color, leaf size, shoot growth, and canopy density, there is no need to fertilize them. In nearly all cases, however, if fertilizer is needed, only nitrogen is necessary, because other nutrients usually occur in adequate amounts in most soil. A notable exception are palm trees, which need potassium in nearly the same amounts as nitrogen. Potassium deficiencies often occur in palms growing on sandy, well-drained soil and those subject to frequent, heavy irrigation, such as occurs in turfgrass areas (see the section "Palms: Selection, Planting, and Management" below).

The use of complete fertilizers (those containing nitrogen, phosphorus, and potassium) is usually not recommended for woody plants because soil is rarely deficient in all three elements. Even if such conditions did exist, it would be difficult to amend the soil satisfactorily with a complete fertilizer. For example, in a potassium-deficient soil, using a complete fertilizer to apply enough potassium would apply too much nitrogen.

Application to the soil surface is the easiest, quickest, and most effective method of applying nitrogen to woody plants. Apply fertilizer under and just beyond the drip lines of trees and shrubs or broadcast it over ground cover plantings. Slow-release forms (organic or synthetic) are usually more expensive than other nitrogen sources, but their use may be justified when application is difficult or must be frequent, because they can be applied less frequently at higher rates. A less concentrated but more continuous supply of nitrogen is available with slow-release forms, which have less likelihood of loss by leaching.

Newly planted, young woody plants (less than 2 years old) and ground covers in the landscape may be fertilized according to the recommendations in table 12.2. When established plantings of trees, shrubs, vines, or ground covers need fertilizer, evenly broadcast about 1 to 3 pounds of actual nitrogen per 1,000 square feet of planted area (shrubs, ground covers, or vines) or per 6 inches of trunk diameter (trees) when plants need it most, usually just before the period of most rapid growth in the spring. Double this rate for trees growing in turf areas, but split the total amount applied into two applications about 6 weeks apart. In either case, a sec-

ond application about 2 months into the growing season may be beneficial. Wash any fertilizer off foliage and keep it away from the trunk or stems of plants. On slopes where fertilizers may be subject to erosion or rolling away, it is best to dibble the recommended amount of nitrogen into 10- to 12-inch-deep holes 2 to 3 feet apart. Follow any fertilizer application with one or two thorough irrigations to move the nutrients into the root zone.

Micronutrients are usually present in the soil in sufficient quantities for adequate plant growth. High pH (above 7.0) and any situations that decrease root activity, such as low soil temperature and damage from disease or poor aeration, may render these nutrients unavailable to plants, and deficiency symptoms may occur. For example, acid-loving (low-pH) plants such as gardenias and azaleas are susceptible to iron deficiency on heavy clay or alkaline soil, especially during cool winter months when soil temperatures are lower. Most plants will grow out of these symptoms with the advent of warmer weather and increased root activity.

Irrigating

Most established woody landscape plants require about 50 to 60% of the amount of water lost by evapotranspiration (ET) to perform acceptably in the landscape. Applying considerably more water may result in excess growth and cause damage to root systems if the soil remains too wet for too long. Similarly, applying considerably less water may cause water stress and injure plants, particularly those that are not native to a dry summer climate.

As noted earlier in "Planting," newly planted woody plants should be frequently irrigated so that the root ball and the soil immediately around them are kept adequately moist during the first season or year of establishment. See chapter 4, "Water Management," for more information.

Designing and Maintaining the Landscape for Fire Protection

As catastrophic fires throughout California in recent years have graphically illustrated, the hazard of brushfires and wildfires for dwellings and urban areas within forests or adjacent to chaparral-covered hills is a serious concern. However, one can have both an attractive and functional landscape and a defensible fire-safe zone around a home. Proper selection, planting, and maintenance of appropriate landscape materials around homes in fire-prone areas can significantly reduce the danger to life and property posed by wildfires. Incorporating fire-safe concepts into the maintenance and design of your landscape is an important way to help your home survive a wildfire.

Importance of Vegetation Arrangement

Plant material is often described according to its vertical and horizontal arrangement or continuity. Vertical fuel is also known as ladder. Wildfires typically begin as surface fires and will not reach the crown of a tree if the vertical fuel continuity is eliminated. If a fire reaches a tree's crown, the heat intensity and flame length are increased and can increase the combustibility of surrounding vegetation and nearby structures. For this reason, keep trees properly pruned and well spaced from a house and readily combustible vegetation.

Horizontal fuel enables a fire to spread across a landscape. Wider spacing of combustible vegetation and incorporating noncombustible landscape elements can greatly reduce fire intensity by breaking up the horizontal fuel continuity. Wider spacing between combustible plants and other combustible items reduces the ability of wind to spread a fire.

Create and Maintain Defensible Space

A fire-safe landscape consists of two zones: the home defense zone and a reduced fuel zone.

Home defense zone

The home defense zone is the area within 30 feet of the house. It should be planted with a few well-spaced and well-pruned single specimens of trees and small groupings of low-growing shrubs among low-growing vegetation and hardscape that will not support the spread of fire to other vegetation or the house. Maintain high moisture in the vegetation and maintain good spacing between trees and the structure. Remove all combustible materials from this zone, such as flammable vegetation, twigs, needles and leaves, woodpiles, and fuel tanks. Keys to creating and maintaining the home defense zone are as follows:

- Carefully place and maintain plants to minimize fire movement to the house. Avoid placing plants or allowing them to grow next to house walls, under eaves, near a deck, or overhanging a structure. Keep branches trimmed at least 10 feet from the roof and remove branches that are close to the ground.
- Select and maintain fire-resistant plants. Mowed lawns, other ground covers, low shrubs, herbaceous perennials, and other plants with naturally high moisture content and kept well watered during dry periods should be featured in the home defense zone.

There is no such thing as a plant that will not burn; all plants will burn given enough heat and other conditions that favor combustion. The cultural practices and landscape management practices (e.g., irrigation, pruning and thinning, plant debris cleanup) have a greater impact on whether a plant is fire resistant than does the species. However, plants can be classified as fire prone or fire resistant.

Traits of fire-prone plants include low moisture content of leaves; small, fine, or needlelike leaves; resinous, aromatic, oily, or waxy leaves or wood; accumulation of dead leaves; and loose or papery bark. Many conifers (pines, cedars, and cypress) and eucalyptus are examples of fire-prone plants. Fire-prone plants can be less susceptible to burning if irrigated regularly and pruned periodically to remove dead or excessive growth.

Traits of fire-resistant plants include high moisture content or fleshy, succulent leaves; large or coarse leaves; lack of resinous, aromatic, oily, or waxy leaves or wood; little or no accumulation of dead leaves; and little or no loose or papery bark. Maples, ashes, roses, and lilacs are examples of fire-resistant woody plants. Other desirable traits include an extensive root system for erosion control, drought tolerance, prostrate or naturally low-growing form, open structure, and ability to resprout after fire. Fire-resistant plants can become susceptible to burning if underirrigated or allowed to accumulate dead or excessive growth.

- Use mulch carefully. Do not place shredded bark or other easily combustible material within 3 to 5 feet of the house. When mulching beds and other open areas with a combustible material, keep the mulch layer no more than about 2 inches deep.
- Use masonry, stone, or other hardscape materials creatively in this zone to create fuel breaks as well as functional and aesthetic landscape elements.

Reduced fuel zone

This zone extends at least 100 feet from the house or to your property line. Wider defense zones are needed if a home is on or near a steep slope or windy exposure. Your insurance company or local fire department may also require additional area be included in the zone. Mature trees in this zone should be thinned so that there is at least 10 feet between the tips of their branches. When planting trees, allow for future growth so that they remain adequately spaced with little or no pruning. Do not use shrubs to screen flammable items such as sheds or propane tanks.

Roses: Selection, Planting, and Management

Roses are easy to grow and have very few pest problems if adapted varieties are selected and properly situated in the gar-

den or landscape. There are many types of roses available to fit most landscape situations in the home garden.

The two broad categories are garden roses and landscape roses. Garden roses include the well-known hybrid teas, floribundas, grandifloras, and climbers and are planted mostly for their flowers. The main garden roses include the following:

Hybrid teas. The most common roses in home gardens today. They form a shrub 3 to 5 feet tall with large, mostly single but spectacular flowers.

Floribundas. Smaller flowers borne more profusely in clusters on a shrub 2 to 4 feet tall. Many of today's newer varieties resemble hybrid teas.

Grandifloras. Intermediate between hybrid teas and floribundas, they combine the large flowers of hybrid teas with the increased bloom production of floribundas; they have long stems on a vigorous shrub 5 to 8 feet tall.

Climbers. Flexible stems to 20 feet long or more need support on a structure, such as a wall, fence, trellis, espalier, pergola, or arbor.

Landscape roses. Sometimes called shrub roses, these are developed for use as general landscape plants and offer several advantages. They possess glossy green leaves, have few thorns, require little pruning and disease and pest control, are well suited for low-maintenance landscapes, grow well under drip irrigation, and do not require removal of old flowers, since petals fall away cleanly. Growing on their own roots and not budded or grafted, landscape roses flower throughout the year, with greatest bloom in midspring and early autumn.

Other kinds of roses include the miniatures and English garden types. Miniatures make good container plants. English roses and certain older varieties have more fragrance than some newer varieties but might not bloom as profusely.

When selecting roses, consider the All-American Rose Selections (AARS). Roses earn this award after 2- to 3-year evaluations in test gardens. AARS designation means that the roses offer some disease resistance and have sturdy growth and exceptional flowers. When selecting roses, look for disease-resistant varieties.

Where and How to Use Roses

Roses require protection from wind and need high light to be healthy and perform best, so pick a wind-protected place in your garden with full sun all day near the coast or with late afternoon shade in hot inland areas. Space roses so there is room to move and work between plants. Do not crowd them, since plants need good air movement for disease prevention. Soil should be well drained but still retain water. Clay and sandy soils are acceptable, but watering must be heavier and infrequent on clay and lighter but frequent on sandy soil. If you have companion plants, choose ones with the same or similar light, soil, and water requirements as roses. Bark mulch or wood chips help to retain soil moisture.

Place roses where their splendid, colorful flowers can be admired from the house. Roses serve double duty in the garden and landscape as providers of cut flowers of legendary quality. The landscape roses fulfill the same garden and landscape roles as most other shrubs. They find use as flowering borders, foreground plants, barriers, ground covers, and even as informal hedges. They are unusually effective when massed, such as in a formal or informal rose garden. Of course, a single, solitary plant with spectacular flowers and without competing plants is an unsurpassed accent or specimen. Miniature roses make fine potted specimens that can be positioned around the garden or patio as needed.

Selecting Roses in the Nursery

Roses are available at the nursery or garden center as either packaged or unpackaged bare-root dormant plants in the winter and early spring or as containerized plants year-round. Avoid selecting packaged plants kept in a warm, sunny

location at the nursery; they might be desiccated or have weak, premature shoot growth. Bare-root plants are usually less expensive, require less care, are easier to handle and plant, and offer a much wider selection of types and varieties.

Containerized plants are more expensive but offer the benefit of showing exactly what the flowers are like if purchased during the blooming period. Also, containerized roses can add instant color to the garden and are useful if one desires an instant full-sized plant to fill an existing gap in the garden or landscape. However, most roses do not thrive in containers, so plants potted the current year are preferred to those carried over from previous years.

Planting

Plant bare-root roses the same day they are purchased; if necessary, they can be stored up to 7 days if left in a cool place and roots are kept moist. Dig a hole large enough to spread the roots evenly without crumpling them. Mound a firm cone of soil in the center of the hole and spread the roots over the cone, taking care to keep the bud union 4 inches above the soil line. Backfill around the roots with unamended soil originally taken from the hole. Settle the soil by inserting a hose and flooding the backfill. Form a watering basin 3 to 4 inches high and about 3 feet in diameter around the plant or place a drip emitter about 6 inches from the stem. Spread a 2-inch layer of mulch in the basin and water thoroughly. For containerized roses, select a plant in at least a 3-gallon container. Dig a hole twice as wide but the same depth as the root ball. Carefully remove the plant from the container and place it in the center of the hole. Continue planting as you would for bare-root plants.

Pruning

The proper time and technique for pruning roses are subjects of controversy. Certain fundamental pruning practices pertain to all garden roses regardless of type:

- Remove any canes that have been broken or damaged by insects or disease.
- Remove one of two rubbing canes.
- Remove spindly canes or those smaller in diameter than the size of a lead pencil.
- Make clean cuts just above a bud or shoot that points toward the outside of the plant (see fig. 12.8).

In most cases, prune roses in January. For garden roses like hybrid teas, floribundas, and grandifloras, cut out all weak, spindly, insect-infested, diseased, and dead stems (canes) and those crossing over others or arising from below the bud union. Leave 6 to 10 canes evenly spaced in a circle around the plant and growing toward the outside, keeping the middle open to form a vase-shaped structure. Cut back these remaining stems or canes, leaving about one-third to two-thirds of the previous year's growth, to a height of 18 to 24 inches or to a height in balance with other plants in the rose bed. Removing more growth gives fewer, larger flowers on longer stems, while removing less growth retains plant size. Make the cut at an outward-facing leaf or bud. Begin each cut about ⅛ inch above the bud or leaf and angle it downward at 45° toward the inside of the cane (see fig. 12.8).

When bare-root roses are planted, the tops should be cut back to 12 to 15 inches. Remove any damaged or broken roots. For containerized roses, these two pruning practices may have been performed before purchase.

Climbing roses should not be pruned for 2 to 3 years after planting, allowing them to become large, well-established plants. At that time select six well-spaced, horizontal, spreading canes and tie them to the support. Remove all remaining canes and any coming from below the bud union. Subsequent annual pruning each January consists of completely removing only old, heavy, and unproductive canes, adding two or three new, main canes to replace those removed. Flowers form on short laterals or spurs arising from the

main canes. Cut these back to three buds at annual pruning. When the canes become quite long, prune them back to keep them in the desired area. Prune strictly spring-flowering climbers after flowering ends, not in January.

Landscape, or shrub, roses require less detailed pruning; prune them mainly to shape and control size. Ground cover roses should be pruned only to remove upright branches.

After pruning, rake up and discard old leaves, twigs, and stems, and spray plants and soil with a dormant spray of oil or lime-sulfur if pests or diseases are problems. Reapply mulch if necessary.

Fertilizing

Roses flower on new growth, which occurs in cyclical flushes throughout the growing season from about March through November. Each cycle begins with a flush of new growth and ends with a flush of blooms. Instead of one or two heavy applications of fertilizer during the growing season, make several light applications, timing them just prior to each new flush of growth. Use a fertilizer with an N-P-K ratio of 3-1-3 or 3-1-2 (e.g., 12-4-12 or 11-4-8). The total amount of fertilizer applied during the growing season should not exceed the recommended yearly amount.

Irrigation and Water Management

Water during the growing season by flooding the basin with 1 to 2 inches of water or using drip or bubbler systems to apply water 1 inch deep when the soil is dry. Avoid frequently wetting the leaves to reduce diseases. However, occasional washing of leaves with a strong spray of water can reduce spider mites, a common pest in warm inland areas, and aphids. Wash leaves early in the morning so they can dry by nightfall. When cutting or removing flowers, cut back far enough to remove at least three leaves and to an outside leaf or bud, while still leaving at least two leaves with five leaflets on the cane. Regularly inspect plants for pests, such as aphids, spider mites, and thrips, and diseases, such as powdery mildew, rust, and black spot.

Palms: Selection, Planning, and Management

Palms give a uniquely dramatic, exotic, and tropical effect to the home yard and landscape and are the signature plants of the California lifestyle. Palms are virtually maintenance-free except for watering and periodic fertilizing and removal of unsightly dead leaves and flower stalks.

Selection

Because their bold lines and striking nature ensure that they are always the center of attention, the proper selection, planting, and care of palms are important. When selecting a palm be sure its form, ultimate size, and adaptability to a particular environment are compatible with the intended site and use.

Palms have two basic leaf shapes and two growth forms (habits) that help to determine their use and placement in the home yard and landscape. They have either fan leaves or feather leaves and either one stem or clumps of several stems. Fan leaves are hand shaped and have the leaf segment radiating from a center point. Feather leaves have leaf segments distributed along both sides of an elongated central leafstalk. Palms with a single stem become treelike, while those with clumping stems are shrub-like. Palms with clumping stems can be made into tree palms by thinning out the clump, leaving only several well-spaced stems and removing lower, older leaves. Similarly, single-stemmed palms can be made to look like clumping palms by planting several closely together in the same hole. Table 12.5 provides a summary of the types of palms and their environmental adaptability.

Because palms are the prima donnas of the plant world, they can easily clash with each other and compete for attention if

used inappropriately, distracting significantly from the desired effect. Avoid planting palms in groups of numerous, indiscriminately massed individuals of the same or different kinds. Instead, use palms informally to draw attention to a particular part of the garden or impart a tropical accent. Employ single-stemmed palms as well for vertical accent while sacrificing little precious ground space to bring into scale large houses or other tall structures or to divide large volumes of air.

Palms in informal settings are most effective if planted individually or, if space permits, in small groups of three or five close but separate specimens of the same kind. Remember that one clumping palm can readily take the place of three to five single-stemmed ones. Use clumping palms as a background or as a screen or barrier to block unsightly views. Employ the same kind and size of palm repetitively in a regular, orderly fashion to achieve a more formal effect, such as lining a driveway, walk, or property boundary. Palms are naturals around water, and their relatively few, large leaves and flower stalks mean a few timely cuts will remove any litter waiting to foul a swimming pool, stream, or pond.

With our ever-diminishing home yards, one must seriously consider the ultimate size and, to some extent, growth rate when selecting palms. Give palms enough space so that when their leaves reach full size they are not clashing with adjacent structures, trees, and other palms. Because palms lack a woody taproot, they make excellent, versatile, long-term potted specimens that can be moved around the garden or yard to best advantage.

Environmental factors to consider when selecting a palm include light, temperature, humidity, and wind. Nearly all large tree palms require full sun for most of the day, while the smaller ones, such as bamboo palms and lady palms, do best in full shade or only part sun. Palms that do best in part sun in hotter inland regions often tolerate more sun in cooler coastal areas.

Some palms are sensitive to cold, and others are sensitive to heat. They will suffer damage or even death if temperatures go too high or low. Temperature-sensitive palms do best in coastal areas with more moderate temperatures. Conversely, other palms tolerate extreme heat and cold, and in California will grow from the desert and interior valleys to the sea. Generally, larger, older, healthier palms are less sensitive to temperature extremes and recover from damage more quickly than do smaller ones of the same kind. No palms are sufficiently hardy to grow in the mountains.

Humidity influences a palm's sensitivity to light and temperature. That some palms are poorly adapted to inland areas is due as much to the less humid, more arid conditions as it is to temperature extremes. Conversely, the California fan palm easily tolerates temperatures in coastal areas but often grows poorly there and has disease problems because of the humid air.

Although most palms are wind tolerant, a few can have their bold, dramatic foliage torn or shredded by wind, detracting considerably from their beauty and ornamental effect. Plant wind-sensitive palms on the wind-protected side of larger trees or shrubs, homes, or other structures. Nearly all palms suffer leaf damage when exposed to constant, often salt-laden sea breezes.

Planting

Container-grown palms can be planted year-round in southern California. Planting procedures are generally the same as discussed in the section "Planting," above. Dig a hole the same depth and twice as wide as the root ball of the palm. Dust the hole with dolomite lime to provide magnesium, a nutrient that palms use in large amounts. Carefully remove the palm from the container and place in the hole. Use the same soil from the hole without any added amendments to backfill around the root ball. Tamp firmly to remove large air pockets but avoid compacting the soil. Mound excess soil to form a water basin 3 inches high and at least as wide as the hole. Place a 2-inch layer of mulch in the

Table 12.5.

PALMS FOR CALIFORNIA

Scientific name	Common name	Leaf	Habit	Height, ft	Width, ft	Growth	Light	Temperature, °F	Wind
Archontophoenix cunninghamiana	king palm	feather	S	30–50	20	M	S	28–105	P
Brahea armata	Mexican blue palm	fan	S	20	10	S	S	20–120	—
Brahea edulis	Guadalupe palm	fan	S	20	15	S	S	20–105	—
Butia capitata	pindo palm	feather	S	20	15	S	S	15–120	—
Caryota mitis	fishtail palm	feather	C	15	15	S	pS	28–105	P
Chamaedorea spp.	bamboo palm	feather	S, C	10	3–6	S	Sh, pS	28–105	P
Chamaerops humilis	Mediterranean fan palm	fan	C	15	15	S	S	20–120	—
Dypsis decaryi	triangle palm	feather	S	15	10	S	S	30–115	P
Howea forsteriana	kentia palm	feather	S	30	10	S	S, pS	28–105	P
Phoenix canariensis	Canary Island date palm	feather	S	60	35	M	S	20–110	—
Phoenix dactylifera	date palm	feather	C, S	60	25	M	S	20–120	—
Phoenix reclinata	Senegal date palm	feather	C	40	30	S–M	S	25–110	—
Phoenix roebelinii	pygmy date palm	feather	S	10	5	S	S, pS	28–105	P
Ravenea rivularis	majesty palm	feather	S	25	12	S–M	S	30–105	P
Rhapis spp.	lady palm	fan	C	12	3–6	S	pS	25–105	P
Syagrus romanzoffiana	queen palm	feather	S	50	12	M	S	25–115	—
Trachycarpus fortunei	windmill palm	fan	S	15	5	S–M	S	10–115	P
Washingtonia filifera	California fan palm	fan	S	60	15	M–F	S	15–120	—
Washingtonia robusta	Mexican fan palm	fan	S	70	10	F	S	15–120	—

Key:

Habit: S = single; C = clumping. Width = the spread of crown of leaves. Growth: S = 1 ft/year; M = 1–2 ft/year; F = > 2 ft/year. Light: S = full sun; pS = part sun; Sh = full shade. Wind: P = needs protection; — = does not need protection.

basin and water thoroughly. Keep the root ball and surrounding soil moist but not wet. Keep grass and weeds away from the stem and root ball.

Management

Unless there is sufficient rain, water palms whenever the top 4 to 6 inches of soil becomes dry. Apply enough water each time to wet the soil to at least 12 inches deep. Use a shovel or probe to check if necessary. Once established, some of the hardy palms can tolerate periods of several weeks or even a month with no added water, especially in the cooler winter months.

Palms require large amounts of nitrogen, potassium, and magnesium and appear especially sensitive to certain micronutrient deficiencies. Macronutrient deficiencies usually occur as a result of insufficient nutrients in the soil. Nitrogen deficiency appears as a general yellowing of all leaves. Potassium and magnesium deficiency appear on the older leaves. Potassium deficiency shows as translucent orange or yellow flecking or speckling, and magnesium deficiency appears as a distinct orange-colored band around the outside of a leaf. Micronutrient deficiencies are on the newest leaves and are usually the result of environmental factors such as damaged roots or improper soil pH, which affect the palm's ability to extract the nutrient from the soil. Iron deficiency shows as chlorosis, while manganese deficiency appears as chlorosis, stunting, and even frizzling. Deficiencies are more easily prevented than corrected by proper fertilization, good soil aeration, proper planting depth, root disease prevention, and proper soil pH. Palms respond

best to a fertilizer with an N-P-K ratio of 3-1-3 or 3-1-2, all in slow-release form, and with magnesium and micronutrients.

Remove leaves once they have begun to turn yellow or brown, and flower stalks once they have completely emerged by cutting them off neatly and as close to the stem as possible, taking care not to damage or scar the stem.

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Home Vegetable Gardening 13

Dennis R. Pittenger
and Nancy Garrison

Learning Objectives

Understand the basic principles of successful home vegetable gardening.

Learn how to plan and plant a vegetable garden.

Know how to care for vegetable crops in the home garden.

Know the basics of culinary herb cultivation in the home garden.

Learn the basics of harvesting and storing home-grown vegetables and herbs.

Learn the basics of problem diagnosis for home-grown vegetables.

Home Vegetable Gardening

Vegetables can be grown in containers, home yards, community garden lots, or large ranch areas. To grow vegetables successfully, observe the following basic rules:

- Plant only as large a garden as you can maintain easily. Beginning gardeners often overplant and fail because their skills and time commitment are not great enough to accomplish the task. Gardening requires weed and pest control and irrigation when needed.
- Plan your garden on paper before you begin.
- Grow crops that produce the maximum amount of food in the space available.
- Plant during the correct season for the crop you plan to grow. Choose varieties recommended for your area.
- Select a site that receives at least 8 hours of full sun each day. It should be relatively level, well drained, and close to a water source. Avoid shaded locations.
- Prepare the soil properly and amend and fertilize as needed.
- Harvest vegetables at their proper stage of maturity. Store them promptly if they are not to be used immediately.

Vegetable Classification

Vegetables can be classified in many ways, but the two most useful ways to gardening are by their growth habit and their temperature requirements. Vegetables are generally classified as annual or perennial crops based on whether they must be replanted each year or will produce crops for multiple years before replanting. Most vegetables are considered annual crops. Common perennial crops are artichoke, asparagus, rhubarb, and many herbs. Consider the long-term space and cultural needs of these crops when planning your garden.

Most vegetables are further classified as cool-season or warm-season crops based on the temperature range in which they grow best and produce the best-quality crops. Consider this when deciding when to plant and harvest crops in the garden. Planting a particular vegetable should be timed so that it grows and matures when normal temperatures are ideal for it to produce a good-quality crop.

Cool-Season Vegetable Crops

Cool-season vegetables grow best and produce the best-quality crops when average temperatures are 55° to 75°F, and they usually tolerate slight frost when mature. Some crops (notably broccoli, celery, carrot, lettuce, onion) in this group are subject to bolting (premature flowering and seeding) if temperatures are too warm as the plant is maturing. The food value of cool-season vegetables is usually higher per pound and per square foot than that of warm-season vegetables, because the edible parts of the plant are the vegetative parts, such as roots, stems, leaves, or immature flower parts, rather than the fruit. Compared with warm-season crops, cool-season crops generally have shallower root sys-

tems, show more dramatic response to nitrogen and phosphorus fertilization, store best at a temperature just above 32°F, and are not susceptible to chilling injury after they are harvested. Examples include

roots: beet, carrot, parsnip, radish, turnip

stems: asparagus, white potato

leaves: cabbage, celery (fleshy petioles), lettuce, onion, spinach

immature flower parts: broccoli, cauliflower, globe artichoke

Warm-Season Vegetable Crops

Warm-season vegetables require long, hot days and warm soil to mature. They grow best and produce the best-quality crops when average temperatures are 65° to 95°F, and they are intolerant of prolonged freezing temperatures. The food value of warm-season vegetables is usually lower per pound and per square foot than that of cool-season crops because the fruit of the plant is eaten. Many warm-season vegetables are actually immature or mature fruits. In other words, vegetables such as tomato and squash are fruits in the botanical sense, just as oranges are a fruit. Examples include

mature fruits: cantaloupe, winter squash, tomato, watermelon

immature fruits: sweet corn, snap and lima beans, summer squash

Planning Your Vegetable Garden

Location

When deciding where to plant your vegetable garden, choose the best available location by keeping the following factors in mind.

Good soil

Although you may have little choice concerning the soil type available to you, you can use a simple test to find out whether your soil is in good condition for planting. Squeeze a handful of soil to test for moisture content. If the squeezed soil forms a clump, the soil is too wet to work. If you work soil that contains this much moisture, it might form into cement-like clumps that can cause problems for the remainder of the year. If the soil crumbles easily when it is squeezed, it is in an ideal condition to work. Tilling or working the soil and incorporating organic soil amendments (such as compost, lawn clippings, or peat moss) can improve poor soil and can increase yield, even in good soil. For more information on amending soil, see the section “Soil Improvement and Preparation” later in this chapter.

Level ground

Level ground is easier to prepare, plant, and irrigate than sloping ground. If you must plant on sloping ground, run rows across the slope, not up and down, to keep the soil from washing away during irrigation.

Water supply

Locate your garden near an abundant supply of water that is easily reached with a garden hose.

Adequate light

Vegetables need at least 8 hours of sunlight each day for best growth. Plant vegetables where they are not shaded by trees, shrubs, walls, or fences. Trees and shrubs also compete with vegetables for the water available in the soil.

Close to home

Plant your garden near your home, if possible. You are more likely to spend time working in your garden if you can reach it easily. A nearby garden also means that you do not have to carry tools back and forth over a long distance. If your garden is large enough for you to use power tools, be sure you have easy access to a road or driveway wide enough for equipment movement.

Efficient Use of Space

The key to any successful garden is planning. Gardeners cannot waste time and

space if they expect to produce large amounts of vegetables from a limited area. Gardeners should pay close attention to timing of planting and harvesting, selection of varieties, trellising, and other space-saving practices.

Timing

Timing refers to the maximum use of the available growing season. Depending on the location in California, there are three to four seasons when vegetables can be grown. Yet many gardeners grow only summer crops. By planting a spring crop, a summer crop, and a fall crop, a gardener can get three crops from the same space. This requires close rotation of crops, such as spring lettuce followed by summer green beans followed by fall spinach. The idea is to plant a cool-season crop, follow it with a warm-season crop, then finish with another cool-season crop. Careful attention to days to maturity for each crop grown will establish the ideal rotation period (see table 13.1).

Trellising and staking

Do not grow horizontally what you can grow vertically. Twining and vining crops, such as tomato, squash, cucumber, and pole beans, use a great deal of space when allowed to grow along the ground. Trellises, stakes, or other supports minimize the ground space used and increase garden productivity. Support materials can be wooden structures, extra stakes, twine, wire cages, or a nearby wire fence.

Spacing

Improved varieties may be the best way for the space-conscious gardener to achieve higher yields. Today, a gardener can select bush varieties of beans, cucumbers, melons, and squash that require much less space than standard varieties. Determinate tomatoes (which grow only to a certain height) produce over a shorter time and can be trained more easily to a stake, whereas indeterminate types must be supported off the ground or trellised but will produce over a longer period. Several bush-type tomato varieties are suited to container culture on patios or other small spaces. The cultivation guide for each vegetable in this chapter notes space-saving varieties.

Succession planting is sowing seed of a given crop at 1- to 2-week intervals to produce a continuous supply of vegetables. Beans, turnips, and beets are well suited to this practice.

Companion planting is planting two crops in the same place at the same time. Normally one crop matures and is harvested before the other. Radishes and carrots work well this way, because the radishes can be harvested long before the carrots are very large. The quick-growing radish seedlings also help to mark planted rows.

Intercropping involves planting early-maturing crops between the rows of late-maturing crops to increase production in a small area. For example, beans, radishes, green onions, spinach, or leaf lettuce may be planted between rows of tomatoes, peppers, cabbage, or corn. The quicker-maturing crops will be harvested before the others become very large.

Proper spacing between rows and within rows is extremely important (see table 13.2 for standard spacing for each crop). However, different spacings may be required in your garden. The use of power equipment requires that the distance between rows exceed the width of the equipment. Maximum production requires wider than standard rows or beds for planting. For instance, seed of many crops, such as leaf lettuce or beets, can be broadcast in a bed 1 to 3 feet across and thinned to obtain proper spacing. Other crops, such as cabbage or broccoli, can be planted closely in wide rows so that their outer leaves touch one another when the plants are about three-fourths mature. These methods reduce space wasted as aisles and often provide such dense shade that weed growth is inhibited and evaporation of soil moisture is reduced.

Raised beds

Raised beds are often helpful in maximizing plant growing space in a garden. They

Table 13.1.

APPROXIMATE DAYS TO MATURITY

Vegetable	Days from planting to maturity under optimal growing conditions	Days from pollination to maturity under warm growing conditions
bean	48–60	7–10
beet	55–70	
broccoli	90–110	
cabbage	65–120	
carrot	120–150	
cauliflower	90–110	
celery (transplanted)	90	
corn, sweet	65–95	18–23 (from 50% silking)
cucumber (pickling)	50–60	4–5
cucumber (slicing)	60–75	15–18
eggplant (transplanted)	60–80	25–40 (2/3 max. size)
kohlrabi	50–60	
lettuce, head	70–90	
lettuce, leaf	40–50	
muskmelon	85–95	42–46
okra	50–60	4–6
onion, dry	90–150	
onion, green	50–60	
pepper (transplanted)	65–80	45–55 (green stage, about max. size); 60–70 (red stage)
potato	90–120	
pumpkin	100–120	65–90 (varies with variety)
radish	21–30	
spinach	40–50	
squash, summer	50–60	4–6
squash, winter	85–110	60–90 (varies with variety)
tomato (transplanted)	60–80	35–45 (mature green stage); 45–60 (red ripe stage)
turnip	45–75	
watermelon	85–95	42–45

provide the advantages noted above for wide beds, plus they improve drainage and can optimize soil otherwise poorly suited for vegetables. To raise beds, add large amounts of topsoil or organic soil amendments so that the bed is established above the previous soil level.

Use lumber or masonry materials to establish and maintain the perimeter of raised beds. Suitable resources include concrete block, stones, untreated cedar or redwood boards, nonarsenical pressure-treated lumber, and plastic composite lumber.

How Much and What Varieties to Plant

Plant enough of each vegetable crop to meet your family's needs for fresh, stored, and preserved supplies. Table 13.2 provides estimated amounts of a crop to plant for a family of four.

For most vegetables, there are a number of varieties (cultivars) from which to choose. When choosing vegetable varieties, consider such factors as disease resistance, maturity date, flavor, compactness of plant,

and the size, shape, and color of the vegetable desired. Keep in mind past experiences with a given variety and compare new varieties with your favorites. Whether purchasing seed or transplants, always note the specific crop variety. Avoid generic or unlabeled transplants, since characteristics can vary widely with different varieties of the same crop.

Vegetable varieties are sometimes described as being either a hybrid (F1) or an open-pollinated (OP) type. Neither type is wholly superior or inferior to the other, particularly for home gardening production. Seed for a hybrid variety is the result of a specific cross between plants of two distinct crop varieties, and the resulting seed produces uniform, often more vigorous plants with desirable traits. Seed collected from a hybrid plant will not necessarily produce plants like the parent. Open-pollinated varieties can produce seed that reproduce plants just like the parent plant for generation after generation. Heirloom vegetable varieties are generally defined as those known through documentation to have been in cultivation at least 50 years and are open pollinated rather than hybrid in origin. Many vegetable crops have at least some open-pollinated varieties, including bean, beet, cabbage, carrot, cucumber, eggplant, lettuce, pepper, squash, and tomato. Heirloom varieties often lack resistance to common diseases affecting a particular crop, while hybrids of the crop often have some degree of resistance.

The University of California has no statewide home garden vegetable variety evaluation programs, so it is not possible to offer a scientifically sound judgment on the suitability of the many newer crop varieties or heirloom varieties that have renewed availability and interest. Additional information on selecting varieties and specific crop variety recommendations are in the section “A Guide for Vegetable and Herb Cultivation in California,” below.

Preparing a Garden Plan

Plan your garden on paper before planting. A well-planned garden can provide fresh or preserved vegetables for use year-round. The plan should contain crops and amounts to be planted, dates of planting and estimated harvest, planting location for each crop, specific spacing between rows, and trellising or support required (see fig. 13.1 and table 13.2 for planting dates in your area of the state). The plan will aid in buying supplies and serve as a handy guide in timing plantings during the season. Plans can be something as simple as planning sweet corn planting dates and variety types to avoid cross-pollination and starchy ears (see discussion in the section “Corn, Sweet,” below) or locating the section of the garden where perennial vegetables will be planted.

First, make a sketch that shows the dimensions of the garden area. Prepare a list of vegetables you want to grow. Then arrange the crops in the garden according to the amounts you wish to grow, dates to be planted, and space available. Plant perennial crops such as rhubarb and asparagus to one side of the garden so they are not disturbed by preparations for future crops. Plant tall crops, such as corn and pole beans, on the north side of the garden so they will not shade low-growing crops.

Tools

Only a few good-quality tools are necessary for a small home garden:

Spade or spading fork. Use to turn the ground, to turn under organic matter, and to break up large clumps of soil.

Rake. Use to smooth out the soil after spading and after preparing the seedbed. It is also useful for clearing up rubbish and removing small weeds.

Hoe or hula hoe. Use to remove tough weeds and to cover seeds after planting; turn sideways to dig a V-shaped row for planting.

Yardstick or tape measure, twine, and stakes. Use to space rows evenly and lay out rows in straight lines.

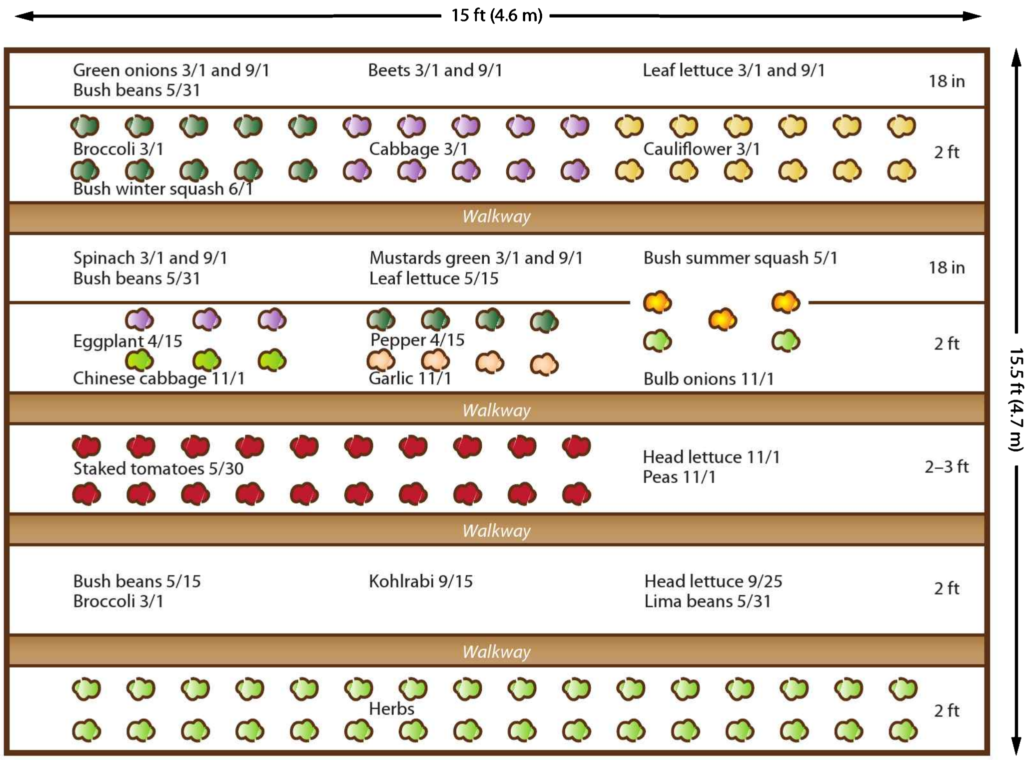


Figure 13.1

Sample garden plan with planting dates and bed widths.

Putty knife or spatula. Handy for blocking out seedlings when transplanting and for cleaning tools.

Small hand sprayer and duster. Use to keep insects and diseases under control.

Trowel. One of the handiest garden gadgets, a trowel is useful for transplanting and for loosening soil around plants.

Dibble. This short, round, pointed stick is used to make holes for transplanting seedlings and to firm the soil around the plant roots.

Care of tools

Following these simple guidelines will keep your tools in good condition:

Clean tools after each use. A putty knife is good for scraping off dirt. If tools get rusty, soak them in oil for a few hours, then use a wire brush or fine sand to scrub off the rust.

Keep cutting tools sharp.

Store tools where you can hang them up out of the way to prevent damage both to you and to them. Keep tools in a dry place to prevent rust.

Preparing for Planting

Seeds and Plants

You can grow many vegetables from seed, but you can also buy young plants from a nursery. Nursery plants are grown from seed under sheltered conditions and are started earlier than you could safely plant the seed outdoors. If you direct-seed vegetables, you must wait for the ground to warm up enough to germinate the seed (see the section “Direct-Seeding and Transplanting Vegetables,” below). Vegetables produced from transplants are usually ready to harvest earlier than those grown from seed. The vegetables most commonly bought as young plants for transplanting are tomatoes, peppers, lettuce, broccoli, celery, cabbage, cauliflower, and eggplant. You can grow these vegetables ahead of the season indoors or in a hotbed or cold frame. For directions for making a hotbed or cold frame and information about seeding and transplanting, see “Growing Vegetable Plants for Early Production,” below.

Buy seeds or plants from a reliable dealer or nursery. If a neighbor has been

Table 13.2.

VEGETABLE GARDENING AT A GLANCE: HOW TO PLANT AND STORE

	Recommended planting dates[a]				General planting requirements				Storage conditions		
							Distance (in)[c]				
Vegetables	North and North Coast	South Coast	Interior Valleys	Desert Valleys	Crop type[b]	Amount to plant (4 persons)	Between plants in rows	Between rows (no beds)	Best tempera-ture (°F)	Time length (weeks)	How to preserve
artichoke[e]	Aug–Dec	May–Jul	Jul	Sep	C	3–4 plants	48	60	32	1–2	freeze whole, can, dry, or freeze hearts
asparagus[e]	Jan–Mar	Jan–Feb	Jan–Feb	Feb–Apr	C	30–40 plants	12	60	32	3–4	can, dry, or freeze
beans, lima[f]	May–Jun	May–Jun	May–Jun	—	W	15–25 ft row	6 bush; 24 pole	30	40	1–3	can, dry, or freeze
beans, snap[f,g]	Jul; May–Jun	Mar–Aug	Apr–May; Jul–Aug	Jan–Mar; Aug	W	15–25 ft row	3 bush; 24 pole	30[h]	45–55	1–2	can, dry, or freeze
beets[f,g]	Feb–Aug	Jan–Sep	Feb–Apr; Aug	Sep–Jan	C	10–15 ft row	2	18[h]	32	3–10	can, dry, or freeze
broccoli[e,f,g]	Feb–Apr; Aug–Sep	Jun–Jul; Jan–Feb	Dec–Feb; Jul	Sep	C	15–20 ft row	9–12	36	32	1–2	dry or freeze
brussels sprouts[e]	Feb–May	Jun–Jul	—	—	C	15–20 ft row	24	36	32	3–4	dry or freeze
cabbage[e,f]	Jan–Apr; Jul–Sep	Aug–Feb	Jul; Feb	Sep–Nov	C	10–15 plants	24	36	32	12–16	dry or freeze
cabbage, Chinese[f]	Jul–Sep	Aug–Oct	Aug	Aug–Nov	C	10–15 ft row	6	30[h]	32	2–3	dry or freeze
cantaloupes and other melons	May	Apr–May	Apr–Jun	Jan–Apr; Jul	W	5–10 hills	12	72	40–45	2–4	freeze
carrots[f,g]	Jan–May; Jul–Aug	Jan–Sep	Aug–Sep; Feb–Apr	Sep–Dec	C	20–30 ft row	2	24[h]	32	16–20	can, dry, or freeze
cauliflower[e]	Jun–Jul; Jan–Feb	Jul–Oct; Feb	Jul–Aug	Aug–Sep	C	10–15 plants	24	36	32	2–3	pickle, dry, or freeze
celeriac	Mar–Jun	Mar–Aug	Jun–Aug	—	C	10–15 ft row	4	24[h]	32	8–16	can, dry, or freeze
celery[e,f]	Mar–Jun	Apr–Aug	Jun–Aug	—	C	20–30 ft row	5	24[h]	32	8–16	can, dry, or freeze
chard[f]	Feb–May; Aug	Feb–May	Feb; Aug	Sep–Oct	C	3–4 plants	12	30	32	1–2	freeze
chayote	—	Apr–May	May–Jun	—	W	1–2 plants	72	use trellis	—	—	use fresh
chives[f]	Apr	Feb–Apr	Feb–Mar	Sep–Feb	C	1 clump	—	—	—	—	use fresh
corn, sweet[g]	May–Jul	Mar–Jul	Mar–Jul; Aug	Feb–Mar	W	20–30 ft in 4 rows	12	36	32	1/2–1	can, dry, or freeze
cucumbers	Apr–Jun	Apr–Jun	Apr–Jul	Feb–May; Aug	W	6 plants	24	48	45–55	1–2	freeze, pickle, or puree
eggplant[e,f]	May	Apr–May	Apr–May	Feb–Apr	W	4–6 plants	18	36	50–60	1–2	dry or freeze
endive[f]	Mar–Jul	Dec–Aug	Jan; Apr; Aug	Sep–Dec	C	10–15 ft row	10	24[h]	32	2–3	use fresh
fennel, Florence fennel	Mar–Jul	Feb–Jul	Aug	Sep–Nov	C	10–15 ft row	6–12	18–30[h]	32	2–3	can, dry, or freeze
garlic[f]	Oct–Dec	Oct–Dec	Oct–Dec	Sep–Nov	C	10–20 ft row	3	18[h]	65–70	24–32	use fresh
kale	Feb–April	Aug–Oct	Aug–Sept	Sept–Nov	C	10 ft row	18–24	24–30	32	2	use fresh
kohlrabi[f]	Jul–Aug	Jan; Aug–Sep	Aug	Oct–Nov	C	10–15 ft row	3	24	32	2–4	use fresh
leeks	Feb–Apr	Jan–Apr	Jan–Apr	—	C	10 ft row	2	24	32	4–12	use fresh
lettuce[f,g]	Feb–Aug	Aug–Apr	Aug; Nov–Mar	Sep–Dec	C	10–15 ft row	12 head; 6 leaf[h]	24	32	2–3	use fresh
mustard	Apr; Jul–Aug	Aug–Feb	Aug; Apr	Oct–Dec	C	10 ft row	8	24[h]	32	1–2	use fresh
okra	May	Apr–May	May	Mar	W	10–20 ft row	18	36	50–60	—	use fresh
onions, bulb[i]	Jan–Mar; Nov–Jan	Feb–Oct	Oct–Nov; Jan–Mar	Oct–Nov	C	30–40 ft row	3	18[h]	32–36	12–32	dry or freeze
onions, green[e,f,g,h]	Apr–Jul	all year	Aug–Dec	Sep–Jan	C	5 ft row	1–2 in	6–12 in	85–90	2–4	use fresh

successful in growing garden vegetables, ask for advice on where and what to buy. Buy fresh seeds. Some seeds, such as onion, parsley, and parsnip, lose viability after about a year. Seed of other vegetables are good for 3 years or more. Companies date their seed packets and may give germination percentages. If the seed is known to keep for several seasons, it may be more economical to buy it in larger amounts. Write the date of purchase on the seed packets and store any leftover seed in a cool, dry place. Do not use any seed for more than 2 or 3 years.

Most vegetable seeds have their best germination potential at the moment they reach maturity on the plant. From that moment they decline in vigor until they can no longer germinate. However, they may continue to germinate well for years if they have been properly harvested and stored.

For more information on starting plants from seed and saving seed from your vegetable crops, see the discussion and tips in

Table 13.2. cont.

VEGETABLE GARDENING AT A GLANCE: HOW TO PLANT AND STORE

	Recommended planting dates[a]				General planting requirements				Storage conditions		
							Distance (in)[c]				
Vegetables	North and North Coast	South Coast	Interior Valleys	Desert Valleys	Crop type[b]	Amount to plant (4 persons)	Between plants in rows	Between rows (no beds)	Best tempera-ture (°F)	Time length (weeks)	How to preserve
parsley[f]	Dec–May	Dec–May	Dec–May	Sep–Oct	C	1–2 plants	8	24	32	1–2	dry or freeze
parsnips	May–Jun	Mar–Jul	May–Jul	Sep–Oct	C	10–15 ft row	3	24[h]	32	8–16	freeze
peas[f,g]	Jan–Apr; Sep–Oct	Aug; Dec–Mar	Sep–Jan; Jan–Feb	Sep–Oct	C	30–40 ft row	2	36 bush; 48 vine	32	1–2	can, dry, or freeze
peppers[e,f]	May	Apr–May	May	Mar	W	5–10 plants	24	36	45–55	4–6	can, dry, or freeze
potatoes, sweet[e]	May	Apr–May	Apr–Jun	Feb–Jun	W	50–100 ft row	12	36	55–60	8–24	can, dry, or freeze
potatoes, white	early: Feb late: Apr–May	Feb–May Jun–Aug	Feb–Mar; Aug	Dec–Feb	C	50–100 ft row	12	30	40–45	12–20	can, dry, or freeze
pumpkins	May	May–Jun	Apr–Jun	Mar–Jul	W	1–3 plants	48	72	55	8–24	can, dry, or freeze
radish[f,g]	all year	all year	Sep–Apr	Oct–Mar	C	4 ft row	1	6[h]	32	—	use fresh
rhubarb[e]	Dec–Mar	Dec–Jan	Dec–Feb	—	C	2–3 plants	36	48	32	2–3	can or freeze
rutabaga	Jul; Mar–Apr	Jul–Sep; Aug–Mar	Aug	Oct–Dec	C	10–15 ft row	3	6[h]	32	8–16	freeze
spinach[f]	Aug–Feb	Aug–Mar	Sep–Jan	Sep–Nov	C	10–20 ft row	3	18[h]	32	1–2	dry or freeze
squash, summer[f]	May–Jul	Apr–Jun	Apr–Jul	Feb–Mar; Aug–Sep	W	2–4 plants	24	48	50–55	2–3	can, dry, or freeze
squash, winter[f]	May	Apr–Jun	Apr–Jun	Feb–Mar; Aug	W	2–4 plants	24–48	72	55	8–24	can, dry, or freeze
tomatoes[e,f]	May	Apr–Jul 15	Apr–May	Dec–Mar	W	10–20 plants	18–36	36–60	55–65	1–2	can, dry, or freeze
turnips[f]	Jan; Aug	Jan; Aug–Oct	Feb; Aug	Oct–Feb	C	10–15 ft row	2	18[h]	32	8–12	can
watermelons	May–Jun	Apr–Jun	Apr–Jun	Jan–Mar	W	6 plants	24–60	60–72	40	2–3	freeze

Notes:

[a]North and North Coast = Monterey County north; South Coast = San Luis Obispo County south; Interior Valleys = Sacramento, San Joaquin, and similar valleys; Desert Valleys = Imperial and Coachella Valleys. Planting dates are for seed unless noted otherwise. Because the areas shown here are large, planting dates are only approximate, as the climate may vary even in small sections of the state. Contact experienced gardeners in your community and experiment on your own to find more precise dates.

[b]C = cool season, W = warm season.

[c]Planting distances listed here are standards. Many crops can be spaced more closely for intensive production.

[d]Adapted from Vegetable Gardening Illustrated 1994.

[e]Transplants, shoots, or roots are used for field planting.

[f]This crop is suitable for a small garden if compact varieties are grown.

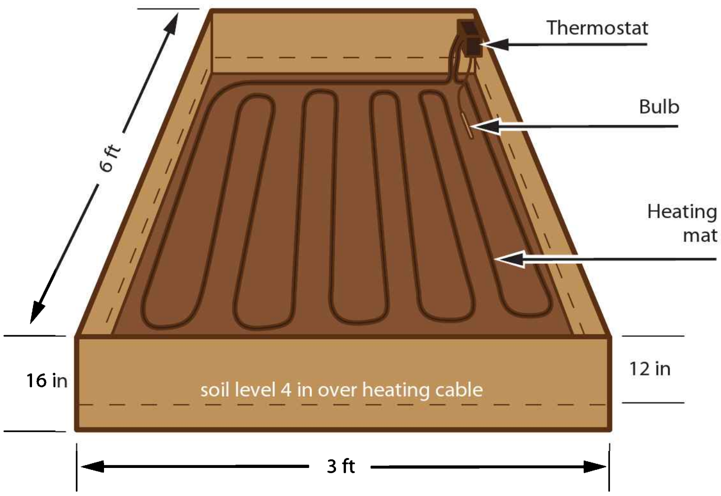
[g]In a suitable climate, these crops can be planted more than once per year for a continuous harvest.

[h]If grown in beds, plant two rows per bed. Space the beds about 32 to 40 in apart and make the tops of the beds 18 in wide.

[i]Planting date depends on the day length requirement of the variety being grown. See discussion in "Onion" section.

Figure 13.2

Diagram of an electric hotbed showing the placement of the heating cable, thermostat, and heat-sensitive bulb, which is used to measure soil temperature. Be sure to cover the heating cable with 3 to 4 inches of soil.



the section "Sexual Propagation" in chapter 5, "Plant Propagation." Information and tips on selecting crop varieties can be found in "A Guide for Vegetable and Herb Cultivation in California," which appears later in this chapter.

Starting Vegetable Plants Indoors

Growing your own transplants indoors can extend your gardening season by several weeks, reduce your gardening costs, and allow you to grow transplants of some of the hard-to-find varieties of crops. In general, seed should be sown from 6 to 8 weeks before the date that you wish to set the plants in the garden. Using tables 13.1 and 13.2, find the appropriate date range for transplanting the crop outdoors, then count backward to determine when you should start the seed. Successful plant starting requires suitable soil mix; suitable containers; proper moisture, temperature, and aeration; adequate light; and conditioning plants to the outdoors. For details on starting plants from seed, see chapter 5, "Plant Propagation."

Growing Vegetable Plants for Early Production

To get a head start on a vegetable garden, you can also start seed in a hotbed or cold frame in order to transplant young plants early in the season. Use any extra space to produce early crops of small vegetables, such as radishes, spinach, and lettuce.

Making a hotbed or cold frame

One 3-by-6-foot hotbed or cold frame sash is enough for the average home garden. Place the sash where there is

- protection from strong, prevailing winds
- good natural drainage
- abundant sunlight
- available water supply

Make the sash frame out of wood, preferably redwood because it withstands weather well. The north end of the frame should be 16 inches deep and the south end 12 inches deep. This design allows water to drain off easily and the sun to heat the soil effectively. Place 4 to 6 inches of good soil in a pit the size of the sash. Add enough good soil so the surface is even with the soil surface at the bottom of the boards.

There are several methods of furnishing supplementary heat to a hotbed: manure, hot air, hot water, steam, and electric heating cable or special heating mats have been used and all can work well. Sometimes light bulbs are used as a source of heat in a small hotbed; they are not effective in heating the soil.

Heating mats or weatherproof electric heating cables are inexpensive means for heating soil and plants in a garden hotbed. A 3-by-6-foot hotbed heated by electric cable commonly uses 1 kilowatt-hour of electricity per day. Use cable of the right length and correct type to deliver 150 to 200 watts to the hotbed. To provide this amount of heat to a 3-by-6-foot hotbed, use 60 feet of number 19, lead-sheathed or similar weatherproof, cut-resistant heating cable. Use a thermostat to control the temperature, because this type of cable can supply about 400 watts at 110 volts of AC current. Lay the cable about 3 to 4 inches below the soil surface. Accurately follow the manufacturer's recommendations for installing the cable. Be careful not to damage the cable when spading the soil in the

hotbed (fig. 13.2). Heating mats placed under trays of plants or plants in individual containers can provide similar benefits.

Of the several materials that can be used to cover a hotbed or cold frame, window glass is the best and the most expensive. More light passes through glass, which keeps the bed warmer than do other materials. Polyethylene plastic also serves as a good sash cover. It is cheaper than glass but must be replaced every year. On cold nights, however, place an additional cover, such as a blanket, canvas, or mats, over the glass or plastic to retain more heat in the bed. Be sure to remove the extra cover during the day.

Plant seeds in the hotbed in rows about 4 inches apart. Cover seeds with about ½ inch of soil. Seeds germinate best at temperatures of 65° to 75°F. You can lower the temperature through ventilation or raise it by using a transparent cover (plastic or glass). Seeds may also be planted in containers filled with soil mix that are placed in the hotbed. When the seedlings emerge, thin them so they are 2 inches apart in the row. Use a pencil or small dibble to thin and to make planting holes. Make sure the seedlings receive plenty of sun and good ventilation. Do not allow the temperature in the hotbed to become too warm; high temperatures cause plants to become weak, leggy, and subject to disease. On warm, sunny days, provide ventilation by propping up the cover at one end of the bed or on the side away from the wind. When transplanting young plants to the garden, take up some soil with each plant as you remove it from the flat. Use a trowel for making planting holes. Lightly firm the soil around each plant, then water gently.

Row covers, hot caps, and similar devices

Another method of promoting early plant growth and production is to cover seeds or young plants in the field with polyethylene row covers, paper hot caps, discarded plastic gallon water or milk containers with bottoms removed, or similar heat-trapping devices. These coverings keep daytime air temperature higher but have limited effect on soil or nighttime temperatures. If you use them, you must harden the plants before completely removing the covering. When the plants start to fill the air space inside the covering, gradually harden the plants by opening the device slightly on the north side. Gradually increase the amount of plant exposure over a week or two. You may take off the covering temporarily for thinning and weeding the seedlings. The covers may must be removed on sunny warm days to prevent them from overheating the plants inside.

Soil Improvement and Preparation

The soil provides plants with air, water, and nutrients. Garden soils are of three general types, or textures. Texture is difficult to change.

Sandy soil is coarse textured and has good drainage, but it retains very little water or nutrients. It is easy to work and irrigate.

Loam and sandy loam soils are of medium texture, easy to irrigate, and usually drain well. These soils are easy to work.

Clay soil is fine textured and usually more fertile and productive than other soil. However, clay soil compacts easily, so it drains slowly. It must not be worked when very wet, and it crusts when dried out. If wet, it takes longer to warm up in the spring.

Soil in good physical condition (good tilth) can hold and provide adequate quantities of nutrients, water, and air to plant roots. It will also drain well when large quantities of water are applied, and it will be easy to work without becoming sticky when wet and crusted when dry. If your garden soil has poor tilth, it can be improved by adding organic matter, such as compost, manure, sawdust, leaves, lawn clippings, or peat moss. Be careful to avoid excessive amounts of organic matter: for example, large quantities of manure can cause excessive salt buildup. Never use lawn clippings recently treated with pesticides. Additional nitrogen fertilizer may be needed when organic matter is used. Cover crops or green manures, such as rye, oats, and wheat, can also improve the condition of soil when they

are tilled under in fall or spring. To produce these crops in time for fall or spring tilling, sow seed in early fall.

The first step in soil preparation is spading, rototilling, or plowing the garden. Do not till the soil if it is too wet, especially if it is clay. In some areas, it is possible to give the garden an early spading before winter rains or frosts occur. If it is not possible to work the soil before winter rains, prepare it as soon as it is dry enough to work easily without resulting in compaction. Work the soil to a depth of at least 6 inches. Immediately after spading, break up large clods with a spading fork or rake to ensure that the soil is pulverized into pea-sized granules. Soil can be formed into beds at this time if desired.

Fertilizing before planting

The basic practices associated with preplant fertilizing are summarized below; more-detailed information on manures and fertilizers, including their analysis, use, and application, is found in chapter 3, "Soil and Fertilizer Management." Vegetables grown in most California soils often require some fertilizer for best growth. In general, the plants will need nitrogen; however, some soils are low in available phosphorus, and a few are deficient in potassium. You can use either organic forms (manures, composts) or inorganic forms (synthetic) to supply needed nutrients. Often, a combination of the two forms gives better results with vegetables than either used alone, particularly if phosphorus and potassium are required in addition to nitrogen.

If you use manure, apply it several weeks or even months before planting and work it well into the soil. This usually allows adequate time for the manure to decompose and some of the manure salts to leach from the surface soil before seeding or transplanting. Adding 1 pound of dry steer or dairy manure per square foot of soil surface is usually sufficient. If you use dry poultry manure, which is more concentrated, apply it more sparingly (1 lb to 4 or 5 sq ft). If you use manure that contains litter (straw, shavings, sawdust, or similar materials), also apply nitrogen fertilizer to avoid tying up nitrogen already present in the soil as well as that being added as manure.

Commercial fertilizers are available in a wide variety of compounds and concentrations. If you use manure or other organic materials, the usual commercial fertilizer need is for nitrogen alone. Nitrogen fertilizers suitable for home garden use include alfalfa meal, cottonseed meal, ammonium sulfate, calcium nitrate, and urea. Limit application of these materials to ½ to 1 pound per 100 square feet whenever they are used.

If you do not apply manure or other organic matter, it is usually wise to apply fertilizer that contains both nitrogen and phosphorus before planting. Ammonium phosphate (16-20-0 or 11-48-0) is one such material. Other commonly used inorganic fertilizers, which contain also potassium, include 5-10-5, 5-10-10, 8-16-16, and 12-12-12. Apply about 1 to 2 pounds per 100 square feet whenever these materials are used, but do not exceed 1½ to 2 ounces (1/10 lb) of actual nitrogen per 100 square feet. Chapter 3 includes some sample calculations for applying fertilizer.

You can apply fertilizer either by broadcasting it before preparing the seedbeds or in bands at seeding time. If you broadcast the fertilizer, work it into the soil fairly soon to prevent nitrogen losses through ammonia volatilization. Sometimes banding is a more efficient way to use fertilizer. To band a fertilizer, first determine where you are going to plant the seed or plants. Then mark the row with a small furrow or a string tied from one end of the row to the other. Dig a shallow trench 2 to 4 inches to one side of the row and 2 to 4 inches below where the seed is to be placed. Place the fertilizer in the bottom of the trench and cover it with soil. To use furrow irrigation, place the fertilizer band between the seed or plant row and the irrigation furrow. To irrigate by sprinkler, band fertilizer on either side of the row. Use 1 to 2 pounds of fertilizer per 100 feet of row.

Time of Planting

Consult table 13.2 for recommended planting dates for the major regions of California. These dates are based on the average temperatures for each region; you may have to make some adjustment if your area varies widely from the average. Unless otherwise stated, the planting times given in the table are for seed. Allow 6 to 8 weeks for seed to produce plants large enough for transplanting.

Temperature is probably the most important climatic factor that affects the success of your garden. Carefully study table 13.2 for information about your area. It will repay you in the yield and quality of the vegetables you grow. Seasonal temperatures are very important in determining when to plant a crop so that it matures when average temperatures are likely to be optimal. Seed of cool-season crops germinate better when soil temperatures are cool than do seed of warm-season crops. (See chapter 5, "Plant Propagation," for details on soil temperature conditions for seed germination of specific vegetable crops.)

Other climatic factors that affect the growth and quality of vegetables are soil moisture and length of day from sunrise to sunset. For example, brussels sprouts and globe artichokes grow more successfully near the ocean, where the humidity is high and temperatures are cool. Many annuals, such as radishes, lettuce, spinach, and Chinese cabbage, tend to produce flowers as the days grow longer in late spring.

Direct-Seeding and Transplanting Vegetables

The standard spacing for various vegetable crops is given in table 13.2. The distance between rows depends on the size of the plants when fully grown. Refer to the section "Efficient Use of Space" in this chapter before selecting spacing distance. The depth of planting, either in the garden or in a hotbed or cold frame, depends on the size of the seed. Plant small seed about ¼ to ½ inch deep. Plant snap bean and sweet corn 1 to 1½ inches deep. A general rule for planting seed is to plant to a depth two to four times the average diameter of the seed.

When setting transplants, plant them slightly deeper than they were growing in the hotbed or flat. Make planting holes large enough so that the roots are not crowded. Be sure to firm, but not pack, the soil around the roots. Water the plants well immediately. An application of 1 to 2 cups of diluted fertilizer solution may help each plant as a starter fertilizer.

Caring for Your Vegetable Crop

Irrigation

Gardens in most areas of California require regular irrigation to provide the soil with the moisture needed for maximum plant growth. Vegetable crops are not drought tolerant. In order to produce good quality and good yields of vegetables, the soil must be kept moist during the crop cycle. During years of normal rainfall, winter rains in most areas usually wet the soil to about 1 foot or more deep by spring. If the soil is not wet to this depth, irrigate before seeding or transplanting so that the soil is wet to a depth of several feet. Irrigation as it applies to home vegetable gardens is presented here in a very brief format.

Avoid creating wide fluctuation in soil moisture content. Fluctuations in soil moisture are particularly injurious to tomatoes, peppers, and other fruits. Fruit cracking of tomatoes often occurs when uneven amounts of water are supplied during fruit expansion. Also, knobs on potatoes result from moisture fluctuations. Most vegetable crops produce poor yields and smaller produce if root systems are allowed to become too dry between irrigations.

As a rule, it will be necessary to irrigate your vegetable garden one to three times a week in summer and once or twice per week or less in other seasons. The frequency will be determined by the depth of crop roots, soil texture, and weather conditions. Wet the soil to just beyond the bottom of

the root system at each watering. If you only keep the surface of the soil moist, most of the water evaporates to the air.

Adjust the amount and frequency of irrigation according to the water use and root depth of each type of vegetable you grow, if possible. When this is not feasible, adjust irrigation to meet the needs of shallow-rooted crops. If their needs are met, the medium- and deep-rooted crops will get enough water. This same rule applies anywhere topsoil is shallow—only 1 to 2 feet of soil is available for root growth, such as in raised beds and many urban properties.

Under ideal soil conditions, shallow-rooted crops have main root systems in the top 6 to 12 inches of soil. Examples are cabbage, cauliflower, lettuce, celery, sweet corn, onion, white potato, and radish. Moderately deep-rooted crops are those with the main root system in the top 1 to 2 feet of soil. Examples are snap bean, carrot, cucumber, eggplant, peas, pepper, and summer squash. For deep-rooted crops, the main root system is in the top 2 to 4 feet of soil. Examples are asparagus, globe artichoke, cantaloupe, pumpkin, tomato, and watermelon.

There are simple ways to measure how much water you give your garden. If you use a garden hose, turn it on to the force you commonly use and time it to find out how many minutes it takes to fill a 1-gallon can. This gives you the rate of water flow per minute. One gallon of water adds 1.6 inches of water when applied to 1 square foot of soil; the depth of soil wetted depends on the soil texture and moisture content at the time water is applied. If you use a sprinkler system, place some empty cans under the sprinkler spray at various spots. Keep track of the length of time the sprinklers are on, then measure the depth of the water in the cans when you turn off the water. Average the various depths to determine how much water is being applied to the garden at each sprinkling.

Furrow irrigation, unlike sprinklers, has the advantage of not wetting the leaves. Water on plant foliage sometimes increases the incidence of plant diseases. If you plan to use furrow irrigation, use raised beds that are 5 or 6 inches high and 32 to 40 inches apart from center to center. Rake the tops of the beds flat and make them 18 to 24 inches wide. Locate the seed rows about 3 inches from each edge of the flattened bed top. Raised beds are also good for winter crops because they allow excess rainwater to drain off. Apply irrigation water in furrows placed between the beds. If you use the furrow irrigation method, you will need to apply more water to wet the soil to the necessary depth than if you use sprinklers or drip irrigation.

Drip irrigation offers several advantages to home gardeners: Water is placed more accurately in the root zone; water is applied at a slow rate, so there is little or no waste; aisles or furrows are dry, so you can work in the garden while irrigation is in process; plant foliage is not wetted; less water is required; and little or no management is required while irrigating. The disadvantages are the added costs of the drip irrigation equipment and occasional problems of plugging of the tiny drip orifices. However, the advantages generally outweigh the disadvantages, and a drip irrigation system, when correctly installed and maintained, can be very helpful to the serious gardener. The emitters in a drip system have a flow rating, such as 1 gallon per hour, and summing the number of emitters will give you the gallons applied to the planted areas. This value can be used as in the sprinkler irrigation discussion above to estimate watering depth.

Soaker hoses are a form of drip irrigation and can be used to advantage if rows are short (20 to 25 ft) and the soil is level. For longer rows or on sloping soil, soaker hoses cannot be expected to provide as uniform an irrigation as that provided by a true drip system.

Fertilizing

Once plants or transplants are well established and at least 3 to 4 inches high, it

may be desirable to sidedress them with nitrogen, particularly leafy crops, in sandy soil, and where you have not applied any manure. Two or three sidedress applications will benefit crops grown for their leaves or other vegetative parts. In crops grown for their fruit, especially tomatoes, yields can be maximized if sidedressing is delayed until the first fruit set and repeated about every 4 weeks until final harvest. Sidedress nitrogen at rates and in a manner similar to those described for banding fertilizer before planting. However, make the trench farther away from the plant row so the nitrogen is not placed close enough to burn plant roots. It is also possible to apply fertilizer through a drip irrigation system. Follow the manufacturer's directions for this type of fertilizer application.

Weeding

Weeds adversely affect crop growth by competing for nutrients, water, and sunlight. The key to successful weed control is to prevent weeds from getting well established. The chief methods of weed control are cultivation, mulching, and hand-weeding. Proper cultivation includes scraping the soil surface or very shallow penetration of the soil with a hoe or other suitable tool to cut off and remove small weeds. Deep cultivation can prune crop roots, which can cause loss of yield.

Mulching offers a potentially more efficient means of weed control, and it also serves to conserve soil moisture. Organic mulches, such as weathered sawdust, straw, lawn clippings, or other such materials, should be applied 2 to 4 inches deep on the soil. These mulches can be tilled under periodically to improve the condition of the soil. Some of these materials will require nitrogen during the decaying process, so apply about 2 pounds of fertilizer per 100 square feet to ensure that adequate nitrogen is available to the mulch and crops.

Weed-block fabric, newspapers, and other such materials can also serve as mulches. They serve the same functions as organic mulches, but they do not offer the soil-conditioning potential of organic mulches. Black plastic can be placed on the soil and properly anchored against wind immediately after the soil is prepared for planting. Transplants can then be set through the plastic by cutting holes just large enough for the plant to fit through.

Thinning

Overcrowded plants cannot grow rapidly or reach a good size. Thin small root crops, salad crops, and those grown for greens early at the second or third true leaf stage. Thin root crops, such as beets or carrots, so the plants are 2 inches apart in the row. Thin radishes so plants are 1 inch apart and head lettuce to 12 inches apart. Table 13.2 lists standard spacing for each crop. However, different spacings may be required in your garden.

Harvesting and Storing

To get the most out of your vegetables, harvest them when they are at the best stage for eating and store them under conditions that will keep them as close to garden fresh as possible. Vegetables will be crisper and cooler if harvested in the early morning. It is best to consume fresh vegetables soon after harvest or purchase. However, this is not always possible, and you may want to store fresh vegetables for a while before using them. It is usually not practical to store most fresh vegetables for long periods at home.

Store fresh vegetables at the right temperature and relative humidity to maintain quality and nutritive value. With few exceptions, fresh vegetables keep best in the refrigerator. Most home refrigerators maintain a temperature of about 40° to 45°F in the main storage space and a slightly cooler temperature in the hydrator (crisper). The door storage areas are warmer.

To prepare vegetables for storage, discard any part that shows evidence of decay. Immediately use any bruised or soft vegetables. Most home-grown vegetables require cleaning before storage. Remove tops of root crops, such as carrots. Wash to remove dirt, then drain excess water thor-

oughly. If you store any vegetables in the refrigerator, but not in the crisper, place them in plastic bags or plastic containers.

Do not put ripe fruits together with vegetables in the crisper. Many ripe fruits produce ethylene gas, which causes yellowing of green vegetables, russet spotting on lettuce, toughening of asparagus, sprouting of potatoes, and a bitter taste in carrots. Cole crops (cabbage, broccoli, and others) give off strong odors that may be absorbed by other commodities; keep them only for a few days in the refrigerator. Root crops, such as radishes, may cause off-flavors in fruits and leafy vegetables; do not store them next to these commodities or store in plastic bags in the refrigerator. Do not store celery with onions or carrots.

Fresh vegetables are grouped into four groups according to storage requirements. Because it is not always possible to provide all these different conditions, make compromises if the storage time is short (a few days).

Group 1

Keep under cold, moist conditions (32° to 41°F and 85–95% relative humidity). Store in the refrigerator crisper and maintain high humidity by keeping the crisper more than half full. Wash and drain vegetables well before storage.

- beet greens
- chard
- collard greens
- endive
- escarole
- green onions
- kale
- leeks
- lettuce
- mustard greens
- spinach
- turnip greens
- watercress

Store the following vegetables in a crisper separate from the above vegetables or in plastic bags or containers in the main compartment of the refrigerator.

- artichokes
- asparagus
- beets
- broccoli
- brussels sprouts
- cabbage
- carrots
- cauliflower
- celery
- lima beans
- mushrooms
- parsnips
- peas
- radishes
- rhubarb
- sweet corn (unhusked; keep close to freezer compartment)
- turnips

Group 2

Ideally, it is best to store these vegetables at 45° to 55°F and 85 to 90% relative humidity because of sensitivity to chilling injury. Because this is not possible in most homes, store in the refrigerator for no longer than 5 days. Use soon after removing from the refrigerator.

- bell peppers
- chili peppers
- cucumbers
- ripe melons
- snap beans
- summer squash

Group 3

Store in a cool place (50°–60°F); lower temperatures cause chilling injury. Pantries, basements, or garages can provide a cool place during most of the year. However, noninsulated garages may be too warm in summer and too cold in winter. If you do not have such a space available, store eggplants and okra as described for the vegetables in group 2; store ripe tomatoes, hard rind squashes and pumpkins, sweet potatoes, and potatoes as recommended for the vegetables in group 4.

Table 13.3.

FAMILIES OF COMMON VEGETABLE CROPS

Family and common name	Scientific name
Amaryllidaceae	
chives	*Allium schoenoprasum*
garlic	*Allium sativum*
leek	*Allium ampeloprasum*
onion	*Allium cepa*
Chenopodiaceae	
beet	*Beta vulgaris*
chard	*Beta vulgaris* var. *cicla*
spinach	*Spinacia oleracea*
Cruciferae	
broccoli	*Brassica oleracea*
brussels sprouts	*Brassica oleracea*
cabbage	*Brassica oleracea*
cauliflower	*Brassica oleracea*
Chinese cabbage	*Brassica oleracea*
kale	*Brassica oleracea*
kohlrabi	*Brassica oleracea*
mustard greens	*Brassica oleracea*
radish	*Raphanus sativus*
rutabaga	*Brassica napus*
turnip	*Brassica rapa*
Compositae	
endive	*Cichorium endiva*
globe artichoke	*Cynara scolymus*
lettuce	*Lactuca sativa*
Cucurbitaceae	
chayote	*Sechium edule*
cucumber (slicing and pickling)	*Cucumis sativus*
muskmelon (cantaloupe, honeydew)	*Cucumis melo*
pumpkin	*Cucurbita pepo*
squash, summer	*Cucurbita pepo*
squash, winter, acorn	*Cucurbita pepo*
squash, winter, butternut	*Cucurbita maxima*
watermelon	*Citrullus lanatus*
Gramineae (Poaceae)	
corn	*Zea mays*
Leguminosae	
bean, dry	*Phaseolus vulgaris*
bean, fava	*Vicia faba*
bean, lima	*Phaseolus limensis*
bean, snap	*Phaseolus vulgaris*
pea	*Pisum sativum*
Liliaceae	
asparagus	*Asparagus officinalis*
Solanaceae	
eggplant	*Solanum melongena*
pepper, bell or chili	*Capsicum annuum*
potato, white	*Solanum tuberosum*
tomato	*Lycopersicon esculentum*
Umbelliferae	
carrot	*Daucus carota*
celery	*Apium graviolens* var. *dulce*
celeriac	*Apium graviolens* var. *rapaceum*
Florence fennel	*Foeniculum vulgare*
parsley	*Petroselinum crispum*
parsnip	*Pastinaca sativa*

eggplants

hard-rind squashes and pumpkins

okra

potatoes (protect from light to prevent greening)

sweet potatoes

Group 4

Store these vegetables at room temperature (65°–70°F). Store them so they are away from direct sunlight.

garlic, dry

melons (unripe or partly ripe)

onions, dry (in open-mesh container)

tomatoes (mature green, partly ripe, and ripe)

A Guide for Vegetable and Herb Cultivation in California

The following notes and tips on selected vegetables and herbs provide an easy-to-use, alphabetical guide that summarizes a wide range of information concerning their culture, harvest, storage, and common problems (pests and diseases). This guide is not intended to be a comprehensive reference source. You will need to consult other vegetable gardening materials to obtain detailed information, which is readily available to the interested home gardener. The guide includes the following features:

Table 13.1: Approximate days to maturity for selected vegetable crops.

Table 13.2: Vegetable gardening at a glance: How to plant and store. This table gives recommended planting dates for various locations in California, a summary of planting requirements, and advice about storage conditions. It also lists a suggested amount to raise for a family of four, the proper temperature for storage of harvested produce, recommendations on the length of time to store, and how to preserve. In addition to this table, UC Cooperative Extension publications on food preservation are also useful resources (see the bibliography at the end of this chapter).

Table 13.3: Families of common vegetable

crops. This table lists the top ten families of vegetable crops grown in home gardens and their scientific names. Note that relatively few plant families are sources of the typical vegetables consumed. As you study the guide, note that similar pests and diseases attack plant families. For example, the cucurbit family (squash, cucumber, pumpkin, cantaloupe, and watermelon) and the cole family (cabbage, broccoli, cauliflower, brussels sprouts) are attacked by similar pests and diseases.

Table 13.4: Approximate yield for selected vegetable crops.

Table 13.5: General problem diagnosis for vegetables. This table lists general problems and symptoms typical of many vegetables grown in home gardens in California.

Table 13.6: Disease resistance key. This table lists the acronyms used in the guide for the pest, virus, or disease to which the recommended varieties are resistant.

Crop varieties (cultivars). The crop varieties recommended in the guide possess attributes important to success in the home garden, including wide availability, adaptability to a range of microclimates,

Table 13.4.

APPROXIMATE YIELD FOR SELECTED VEGETABLE CROPS

Crop	Pounds (or units) per 15 ft row
asparagus	4–5
bean, lima (bush)	4
bean, snap (bush)	15
beets	40 (2 rows on raised bed)
broccoli	11
carrot	40 (2 rows on raised bed)
cabbage	22
cauliflower	15
chard	11
corn	18 ears
cucumber, slicing	40 (2 rows on raised bed)
cucumber, pickling	27
garlic	6
eggplant	15
kohlrabi	11 (2 rows on raised bed)
lettuce, head	15 heads (2 rows on raised bed)
lettuce, leaf	15 (2 rows on raised bed)
muskmelon	15 melons
mustard greens	22 (2 rows on raised bed)
okra	16
onion, bulb	34 (2 rows on raised bed)
pea	3
pepper, bell	20
potato, sweet	30
potato, white	36
spinach	20 (2 rows on raised bed)
squash, summer	52
squash, winter	45
tomato	42
turnip	27

Table 13.5.

GENERAL PROBLEM DIAGNOSIS FOR VEGETABLES

What the problem looks like	Probable cause	Controls and comments
poor fruit yield; small fruit with poor taste	uneven moisture	Supply moisture during dry periods.
	poor soil fertility	Add compost or well-composted manure.
	improper temperature	Plant at right time of year.
plants grow slowly; light green leaves	insufficient light	Thin plants; do not plant in shade.
	cool weather	Provide hot caps, floating row cover.
	improper pH	Test for pH. If alkaline, add soil sulfur, aluminum sulfate, peat moss.
	excess water	Do not overwater. Improve drainage by adding amendments and/or building raised beds.
seedlings do not emerge	insufficient soil moisture	Supply water.
	soil crusting	Apply light mulch to soil surface or water often enough to keep surface moist.
	damping-off (fungal problem)	Do not overwater. Use treated seed.
	incorrect planting depth or seeds washed away	Use gentler watering technique.
	slow germination due to weather	In spring or fall, cover bed with clear plastic to increase soil temperature.
	root maggots	Use registered soil insecticide. Use floating row cover as exclusion.
	old seed	Use current season seed.
seedlings wilt and fall over	dry soil	Supply water.
	damping-off (fungal disease)	Do not overwater. Treat with fungicide.
	cutworms	Destroy crop residues; keep garden weed-free. Use cardboard collars, floating row covers.
	root maggots	Use floating row cover as exclusion; use soil insecticide.
	old seed	Use current season seed.
chewed seedlings, plants, fruit	birds, rodents, rabbits	Place fence around garden; cover with netting, floating row cover.
leaves stippled with tiny white spots	spider mites	Treat with registered miticide or insecticidal soap spray.
	air pollution (ozone)	Wash off foliage.
wilted plants	root rot (fungal disease)	Do not overwater. Remove old plant debris. Rotate crops.
	vascular wilt (fungal disease mainly affecting tomato, potato, eggplant, pepper)	Use resistant varieties. Use soil solarization techniques. Rotate crops.
	root knot nematodes	Use resistant varieties. Use soil solarization techniques. Rotate crops.
	various root-feeding nematodes	Submit soil sample for nematode analysis. Use soil solarization or fumigation.
	waterlogged soil	Improve drainage.
general leaf yellowing; no wilting	nutrient or mineral deficiency	Test soil for deficiencies. Add complete fertilizer.
	insufficient light	Thin plants to reduce shading. Move to sunnier garden location.
leaf margins turn brown and shrivel	dry soil	Supply water.
	salt damage	Do not place garden where de-icing salt may have been applied on nearby concrete. Keep salty water off foliage. Leach with good-quality water.
	fertilizer burn	Do not overapply fertilizer. Flush soil with water. Test soil for soluble salts level.
	potassium deficiency	Test soil for deficiency. Apply potassium fertilizer, compost, or manure.
	cold injury	Protect from cold with hot caps, floating row cover.
discrete brown spots on leaves	chemical injury due to local application or drift	Do not apply chemicals that are not registered for use on the plant. Apply chemicals at registered rate.
white powdery growth on upper leaf surface	powdery mildew (fungal disease)	Choose resistant varieties. Use Safer's sulfur with surfactant.
leaves shredded or stripped from plant	rodents, deer, hail damage, or slugs	Place fence around garden. Use slug bait.
leaves with yellow and green mosaic or mottle pattern; puckered leaves; stunted plants	virus disease	Use resistant varieties if possible. Remove infected plants. Remove old plant debris. Practice insect and weed control.
curled, puckered or distorted leaves	herbicide injury	If you use lawn herbicides, apply after wind has died down. Do not apply herbicides in the heat of the day.
	virus disease	Use resistant varieties if possible. Remove infected plants. Remove old plant debris. Practice insect and weed control.
	aphids	Use soap-based spray, floating row cover.

Table 13.6.

DISEASE RESISTANCE KEY

Abbreviation	Disease
A	Alternaria diseases
AAS	All-America Selection (hardy in most areas, resists most diseases)
ALS	angular leaf spot
AN	anthracnose
B	bolting
BR	black rot
BS	black speck
BSR	bacterial soft rot
BW	bacterial wilt
C	*Cercospora*-caused diseases
CBM	common bean mosaic virus
CMV	cucumber mosaic virus
DM	downy mildew
F	Fusarium diseases
H	heat
HS	hollow stem
LB	late blight
LMV	lettuce mosaic virus
M	mosaic virus
N	root knot nematode
PM	powdery mildew
PVY	potato virus Y
R	rust
S	scab
SCLB	southern corn leaf blight
SG	smog
ST	smut
SW	stewart's wilt
TB	tip burn
TMV	tobacco mosaic virus
V	Verticillium diseases
VR	other viruses
?	disease reaction unknown

consistency of high-quality yields, and resistance to disease. Where several varieties are listed for a crop, you may want to grow more than one to determine which is best suited to your locality and your individual taste. If you are uncertain about which variety to plant, choose a variety designated AAS. These All-America Selections perform well throughout most of the United States, and many are resistant to disease. Printed and online seed catalogs or other information from seed companies may be helpful in describing characteristics of varieties; or, contact your local UC Cooperative Extension office and the UC California Garden Web, ucanr.edu/sites/gardenweb/, for help in selecting varieties suited to your area.

Culture and management. For each crop there are general guidelines, cultural practices, and special tips for successful production.

Problem diagnosis. For most vegetable crops, the guide offers crop-specific problem diagnosis information that includes a list of the most common diseases, insect pests, and cultural problems that home gardeners may experience. Also included, where appropriate, are more detailed comments about fruit set problems in squash, melon, tomato, and cucumber in home gardens; fruit drop problems, solar yellowing, and leaf roll disorder in tomatoes; premature heading in cauliflower and bitterness in cucumbers; and environmental factors that cause problems in cultivating radishes. The few crops for which there is no crop-specific pest and problem diagnosis information seldom have serious problems; consult table 13.5 and other UC references if pests or other problems are encountered in them. Up-to-date information on the management of many specific pests, including possible pesticide remedies, can be found in the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden.

Comprehensive information about managing vegetable pests, weeds, diseases, insects, mites, snails, slugs, and nematodes in

California is available in *Pests of the Garden and Small Farm* (Flint 1998), which is recommended as an essential resource and reference book for master gardeners. See chapter 9, "Safe and Sustainable Pest Management," for general information on pest management and pesticide safety. For more specific advice about crop culture or pest and disease control, contact your UC Cooperative Extension advisor or master gardener office. In most cases, the guide in this handbook should provide enough know-how to get a crop from seed to harvest.

Artichoke, Globe *(Cynara scolymus)*

Recommended Varieties

- Emerald
- Green Globe
- Imperial Star (spineless, for annual cropping)

Perennial plantings

The globe artichoke is commonly a perennial cool-season vegetable that yields and produces best when grown near or along the California coast where cool to mild climates prevail; Castroville, California, is known as the artichoke capital of the world. Perennial plantings are not recommended in areas where warm to hot temperatures are common. Shading and mist irrigation may help vegetative growth, but warm growing conditions tend to toughen bud scales, reduce palatability, and produce poor yields. Frosts damage outer portions of the buds; severe or frequent frosts damage or kill the plants. If correctly cared for, you can maintain production in a plant for 5 years or more.

Use rooted offshoots or divisions from mature plants to propagate Green Globe. The other varieties may be obtained from seed or transplants. Plants establish better if you transplant shoots, root divisions, or transplants in the early fall so that the plants become well rooted and of reasonable size before temperatures cool during the winter. Production starts about a year after planting, although some buds usually develop the first spring after early-fall plantings.

Once the plant is in normal cycle, bud production starts in the fall. A small number of buds develop during the winter, but cold temperatures limit plant growth. The edible parts are the immature, scaly flower buds and bracts (leaves), along with the heart. The buds are said to contain a chemical that makes food eaten after them taste sweet. Mature artichoke flowers are a brilliant sky blue color, but they are not edible.

To harvest, cut the bud together with 2 to 3 inches of stem. This length of stem is

Problem Diagnosis for Artichokes

Problem	Probable cause	Comments
Holes, discoloration on bracts, stems, leaves. Caterpillars may be visible.	artichoke plume moth	Cut plants down to ground level once per year. Chop and cover cuttings with 6 in of soil. Remove thistle. Consult UC IPM Pest Notes or Flint 1998 for management options.
Sticky exudate on chokes. Black, sooty mold.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Blackening of choke surfaces. Jagged holes in leaves, stems.	snails and slugs	Consult UC IPM Pest Notes or Flint 1998 for management options.
Curled leaves, dwarfed plant. Small, misshaped chokes. Reduced yield.	curly dwarf virus	Remove and destroy infected plants immediately. Use noninfected stock for new plants. Remove milkthistle because it is an alternate host.
Gray or brown fungus growth.	*Botrytis* fungus	Common in rainy weather. Remove infected plant parts.

usually tender and edible. A mature plant produces 10 or more stems during a season; each stem can provide four to five buds.

A recommended cultural procedure is to cut the entire plant down to the soil level or slightly below it after the spring production peak. Then, reduce or withhold irrigation for several weeks. This allows for a summer dormancy. Once you resume irrigation, it encourages rapid and vigorous regrowth of leaves and, shortly thereafter, new stems bearing new buds will develop for the fall production period.

Annual plantings for inland valleys and low desert regions

It is possible to grow high-quality artichokes in the inland valleys and low desert regions of southern California by handling them as a direct-seeded or transplanted annual crop. Until recently, it was believed that artichoke buds produced from seed-propagated plants were of inferior quality to those produced by vegetative propagation. Research at the University of California, however, has shown that seed-initiated artichokes look and taste just as good as those produced vegetatively. Moreover, annual cropping makes growing artichokes feasible in gardens with limited space because the crop does not require long-term space allocation. Quicker rotation with other vegetables is also possible. To grow artichokes in warm inland climates, plant seed or transplants of Imperial Star or Emerald in July for inland valley locations or in September for low deserts. Production can be expected anytime between January and April, as dictated by local climate.

Asparagus *(Asparagus officinalis)*

Recommended Varieties (Disease resistance, table 13.6)

- 500W
- Mary Washington (R)
- UC72 (F)
- UC157 (F)

Asparagus is a very hardy, perennial, cool-season vegetable that can live 12 to 15 years or longer. It is one of the most valuable early vegetables and is well adapted to freezer storage. During the harvest period, spears develop daily from underground crowns. Asparagus does well where winters are cool and the soil occasionally freezes at least a few inches deep.

Start asparagus from seed or 1- to 2-year-old crowns. (The crowns are rhizomes—fleshy stems that store food for future plant growth—with roots attached on their undersurface and the buds of emerging spears sticking up.) For best results, buy crowns from a respectable nursery. Starting plants from seed requires an extra year before harvest. Seed may be started in peat pots; they are slow to germinate, so be patient. Seedlings may be transplanted in fall. Crowns are usually set out in winter or early spring. See table 13.2 to determine the best planting dates in your area of the state.

Choose a site with good drainage and full sun. The 3-foot-tall ferns of asparagus may shade other plants, so plan accordingly. Prepare the bed as early as possible and enrich it with additions of manure, compost, bonemeal or blood meal, leaf mold, or wood ashes or a combination of several of these. In heavy soil, double digging is recommended. To double-dig, remove the top 1 foot of soil from the planting area. Then, with a spading fork or spade, break up the subsoil by pushing the tool into the next 10 to 12 inches of soil and rocking it back and forth. Do this every 6 inches or so. Double digging is ideal for the trench method of planting asparagus. The extra work of breaking up the subsoil will be well worth the effort, especially in heavy soil. The trench should be dug 12 to 18 inches wide, with 4 to 5 feet between trenches. The same method may be used in wide-bed plantings, with plants staggered in three rows. Mix the topsoil that has been removed with organic matter (ideally, well-rotted

manure) and spread about 2 inches of the mixture in the bottom of the trench or bed. Set the plants 12 inches apart, mounding the soil slightly under each plant so that the crown is slightly above the roots. Crowns should be a grayish brown color, plump, and healthy looking. Remove any rotten roots before planting. Spread the roots over the mound of soil and cover the crown with 2 to 3 inches of soil. Firm well. As the plants grow, continue to pull soil over the crowns (about 2 inches every 2 weeks) until the trench is filled. Water if rainfall is inadequate.

Asparagus takes several years to mature. Asparagus shoots (spears) should not be harvested the first season after crowns are set. After spears shoot up, let them leaf out so that the foliage can nourish the growing roots and rhizome for future production. Harvest lightly for 3 to 4 weeks the second year. The fleshy root system still needs to develop and store food reserves to support perennial growth in future seasons. Plants harvested too heavily and too soon often become weak and spindly, and the crowns may never recover. Add an extra year to the above schedule for asparagus started from seed; that is, do not harvest at all the first two seasons, and harvest lightly the third. When the asparagus plants are in their fourth season, they may be harvested for 6 to 10 weeks per year.

Weed the bed each spring before the first shoots come up to avoid accidentally

Problem Diagnosis for Asparagus

Problem	Probable cause	Comments
Pustules on stems and leaves are reddish brown, orange, or black. Tops turn yellow, brown, and die back.	rust	Caused by a fungus. Prevalent in humid areas. Use resistant varieties. Cut down diseased ferns at crown and destroy. Consult UC IPM Pest Notes or Flint 1998 for management options.
Spears weaken, wilt, turn yellow and then brown; roots reddish.	Fusarium wilt	Caused by soilborne fungus. Destroy infected plants. Plant resistant variety or use soil solarization methods. Disease can be introduced on transplants. Rotate planting area.
	root rot fungi	Rotate crops. Remove plant debris. Plant in well-drained area.
Bent spears; drought-stricken and white or light green.	Phytophthora crown and spear rot	Common in wet years.
Chewed leaves; slime on leaves.	snails, slugs	Use commercial snail bait. Put mushrooms in garden as attractant. Use flashlight; collect and kill any found. Apply copper banding as barrier around beds.
Black stains on spears. Black eggs attached to spears.	asparagus beetle	Adult is a blue-black beetle; larva is a dark green–gray grub about $^3/_8$ in long. Promptly remove infected spears. Wash eggs, beetles, and larvae off with water. Consult UC IPM Pest Notes or Flint 1998 for management options.
Weak, spindly plants. Too few spears.	too early or too heavy harvest; weed competition; frost injury; drought	Do not harvest too late in season; plants will not be able to store enough food for next season. Allow plants to recover. Mulch soil to prevent freezing.
Fine whitish or yellowish stippling on shoots.	spider mites	Consult UC IPM Pest Notes or Flint 1998 for management options.
Stunted, rosetted plants. Aphids on young ferns.	European asparagus aphid	New pest that invaded California in the 1980s. Incorporate ferns into soil in fall to destroy eggs.

breaking off spears. During production, it is best to pull rather than hoe weeds, if possible.

Harvest spears daily during the harvest period; use the asparagus or refrigerate it immediately in a plastic bag. The 6- to 8-inch spears are best and should be snapped or cut off just below the soil surface. If the asparagus is allowed to get much taller, the bases of the spears will be tough. Cutting too deeply can injure the crown buds that produce the next spears. Blanched asparagus is a gourmet item; to blanch (whiten) the spears, mound soil around them or otherwise exclude light from them so that chlorophyll is not formed in the stalks.

When harvest is over, allow the spears to grow and leaf out. Asparagus has an attractive, tall fern-like foliage that makes a nice garden border. Some gardeners prefer to support the growing foliage with stakes and strings to keep it tidy. In high-wind areas, plant the rows parallel to the prevailing winds so that plants can support each other.

There are several ways to extend the harvest period of your asparagus planting. One method is to plant at different depths: 4 to 6 inches, 6 to 8 inches, and 8 to 10 inches. The shallow plantings will come up first and can be harvested while the deeper plantings are just forming. This method results in a slightly longer harvest, but it may also cause some plants to be less vigorous than others.

A second technique for extending asparagus harvest has been the subject of university research and is highly recommended for home gardeners who have plenty of space. Plant double the amount of asparagus needed for your household. Harvest half of the plants as you normally would in early spring; then allow the foliage to grow for the rest of the season. During the early-harvest period, allow the ferns to grow in the other half of the asparagus planting. Then, cut the ferns in this second half in July or August. This causes the crowns to send up new spears, which can be harvested until late in the season. If rainfall is short in summer, it helps to water the bed for good spear production. A light mulch helps keep the soil surface from becoming too hard for the shoots to break through easily. If using this method, harvest the spring bed only in spring and the fall bed only in fall. Otherwise, you risk weakening the crowns.

In all asparagus plantings, cut the foliage down to 2-inch stubs after freezing weather or when the foliage yellows. A 4- to 6-inch mulch of compost, manure, leaves, or other material added at this time will help control weeds and add organic matter and nutrients.

Beans

Glycine max (soybean)

Phaseolus coccineus (scarlet runner bean)

Phaseolus lunatus (lima beans)

Phaseolus vulgaris (snap beans, dry beans)

Vicia faba (fava bean, broad bean)

Vigna unguiculata (southern pea, cowpea)

Recommended Varieties (Disease resistance, table 13.6)

Bush yellow

- Goldcrop Wax (AAS, CBM)
- Resistant Cherokee Wax (CBM)

Lima

- Fordhook 242 Bush (AAS)
- Henderson's Bush (pole type)
- King of the Garden (bush butterbean type)
- Dixie Butterpea (butterbean type)
- Baby Fordhook Bush (butterbean type)

Snap-bush green

- Contender (CBM, PM)
- Harvester (CBM)
- Roman (CBM)
- Tendercrop (CBM, PM)

Snap-pole green

Fortex

Emerite

Kentucky Wonder (R)

Romano (Italian type)

Scarlet Runner (attractive scarlet flowers)

Kwintus

Beans are tender, annual, warm-season legumes that fix their own nitrogen once a good root system is established. Although they are warm-season plants, snap and lima beans experience blossom drop and poor pod production when temperatures are above 90°F. Water stress and air pollution also reduce yields of these crops. Snap beans (also known as green or string beans) that are grown for their pods are the most commonly grown. Some beans, such as limas, soybeans, and dried beans, are grown primarily for the seed and not the pods.

Many bean varieties are available in both bush and pole types. Bush varieties mature early and do not require trellising, and some are more heat tolerant than pole types. Bush varieties have a concentrated production period of 2 to 3 weeks and produce fewer beans than pole varieties, which produce for 4 to 6 weeks. Bush snap beans are the most popular variety. Snap bean varieties include standard round- and flat-podded green, yellow wax, and purple-pod types, giving gardeners a larger choice than is generally available in supermarkets. Although wax beans are yellow and waxy in appearance, their flavor is only subtly different from that of regular green snap beans. Purple-pod beans are purple while growing, but the pods turn green when cooked. Flat-pod green snap beans are somewhat different in flavor and texture than the round-pod beans and are preferred by many gardeners.

First plantings of bush beans should be made in the spring after the danger of frost is past and the soil has warmed; seed planted in cold soil germinate slowly and are susceptible to rotting. Seedlings also may grow slowly in cool temperatures. Plant two crops of bush beans 2 to 3 weeks apart for a longer harvest. Snap beans should be kept picked to keep plants producing heavily. Harvest snap beans when the pods are full sized. The pods will break easily with a snap when they are ready. The seed should not cause the pods to bulge.

Half-runner beans have a growth habit between that of bush and pole beans, and although they have runners about 3 feet long, they are generally grown like bush beans. Trellising, however, may increase production of this heavy-yielding variety.

Pole-type beans come in many varieties, generally bearing over a longer period than bush types and yielding more in the same amount of space because they require trellising. Pole beans are natural climbers but will not interweave themselves through horizontal wires. A tripod support can be made with three wooden poles or large branches that are lashed together at the top. Five or six seed are planted in a circle 6 to 8 inches from each pole. Many types of homemade trellises work well as long as they provide the needed support. Trellises should be 6 to 8 feet tall and sturdy enough to withstand strong winds and rain.

Scarlet runner beans are a type of pole bean that is quite ornamental as well as productive and delicious. The vines grow rapidly to 6 to 15 feet, producing beautiful red flowers and beans, which may be harvested as snap beans when young or as green shell beans later. Beans are ready to pick in 75 to 85 days, and several pounds are produced per plant. The value of scarlet runner beans is mainly ornamental, although the lush vines can cover arbors, trellises, or fences. An added feature is that the flowers are attractive to hummingbirds. According to some catalogs, the scarlet runner bean grows best in cooler weather than standard beans prefer; in some very hot areas, the vines may not keep producing all summer, as they will in cooler regions. Keeping maturing beans

picked prolongs the life of the vines.

Lima beans are available in bush or pole types. Bush limas mature more slowly (65–75 days) than do snap beans (50–60 days) but about 10 to 15 days earlier than pole-type limas. Pole limas have better yields and produce longer than do bush forms. The soil temperature must be 65°F for 5 days for lima beans to germinate well. Because the large seed store considerable amounts of carbohydrates, limas are quite susceptible to soil fungi and bacteria, which find these foods as nutritious as we do; the sooner the seedling starts using the stored food, the better. Seed treated with antifungal agents have higher germination rates. Soil should be kept moist (but not soaking wet) until the seedlings come through the ground; do not allow a crust to form on the soil, because the seedlings will have trouble pushing through. Prevent crusting and conserve moisture by spreading a light mulch over the seeded row. A cold, wet spell can cause lima flowers to drop, as can excessively hot and dry periods, reducing yields. Baby limas, also known as butter beans, are less susceptible to blossom drop problems. Harvest lima beans when pods are bright green and the seed are full sized. The ends of the pod will be spongy.

Southern peas are used in the same ways as beans and peas, although they are in a separate genus. Three commonly grown types are black-eyed pea, cream pea, and crowder pea. Southern peas may be harvested in the green shell or in the dried pea stage. The yard-long, or asparagus, bean is related to black-eyed peas and has similar flavor, but the entire pod may be eaten. On trellised vines, pods may be produced that are 1½ to 2 feet long. Asparagus beans need warm temperatures and a long growing season to do well. Look for seeds in novelty, gourmet, Asian, or children's sections of seed catalogs.

Soybeans are increasing in popularity in home gardens because of their high nutritional value (protein content) and versatility. Catalogs often list them as edible soybeans; all soybeans are edible, but those in garden catalogs have been bred to do well under ordinary garden conditions, requiring a shorter season and not growing as tall as the field types. There is also a difference in flavor and texture, as there is between sweet and field corn. Soybeans are less sensitive to frost and may have fewer insect problems than standard beans. Soybeans are quite delicious when harvested as green shell beans but may also be allowed to dry on the vine. The pods of soybeans are difficult to open; cook for a few minutes to soften the pod before removing the beans.

Many beans that can be consumed green dry well and are used primarily as dried beans. In a small garden, growing dry beans is somewhat impractical, because a great amount of space is required to raise a large enough quantity for storage. Many types of dry beans may be purchased in supermarkets at a very low cost, so it may be more worthwhile to grow higher-value crops in the limited space. However, if you have a very large garden area and a desire to sit on the front porch rocking away and shelling beans in the fall, they are worth a try. Some varieties available to gardeners are either rare or completely unavailable in the supermarket.

The horticultural (October) bean is very widely grown in parts of the state. The colorful pods and beans of the horticultural bean make it an attractive addition to the garden and kitchen. The seed of pinto beans look similar to those of the horticultural bean but are smaller. They are used widely as brown beans and as refried beans in Mexican dishes. Black beans, or black turtle beans, make an unusual, delicious black-colored soup. They are easy to grow if given plenty of air movement to prevent the disease problems to which they are susceptible. Kidney beans are the popular chili and baking bean, available in deep red or white types. Navy pea and Great Northern beans are used in soups and as baked beans.

Problem Diagnosis for Beans

Problem	Probable cause	Comments
Rotten seed, or seedlings collapse soon after they come up.	damping-off fungi; seedcorn maggot	Fungi can rot seed or seedlings. Do not plant in cold, moist soils.
Yellow leaves; weak, wilted dying plants; sunken, red oval spots at base of stem.	Rhizoctonia root or stem rot	Favored by warm soil temperatures. Remove old plant debris. Rotate crops. Consult UC IPM Pest Notes or Flint 1998 for management options.
Wilted, stunted plants; yellow leaves.	wet or dry soil; poor fertility	Provide good drainage. Do not overwater. Irrigate properly. Mulch in summer. Incorporate compost or manure before planting.
Plants wilt, turn yellow. Roots and belowground stems have red spots that turn brown and decay.	Fusarium root rot	Caused by soilborne fungus. Destroy infected plants. Use soil solarization methods. Disease can be introduced on transplants. Rotate planting area.
Fine whitish or yellowish stippling on upper leaf surface. Fine grayish webbing on undersurface of leaves. Leaves look burned when heavily infested.	spider mites	Irrigate adequately. Wash mites off leaves. Consult UC IPM Pest Notes or Flint 1998 for management options.
Curled, deformed leaves. Black sooty mold. Leaves shiny from honeydew. Plants may be stunted.	aphids	Use soap spray. Control ants with sticky barrier. Consult UC IPM Pest Notes or Flint 1998 for management options.
White stippling on upper surface of leaves with tip and margin burn. Undersurface of leaves shows small, white cast skins of insects.	leafhoppers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Yellow leaves with black sooty mold; leaves shiny from honeydew. Clouds of tiny white insects fly when plant is disturbed.	whiteflies	A nuisance that does not reduce yields.
Stunted seedling plants with distorted leaves; yellowed leaves.	thrips	Adults are tan to black and look like slivers of wood; young are yellow. Feed on plant growing points. Larger plants less affected than seedlings. Plants will outgrow and recover.
Holes, skeletonized areas on leaves, flowers. Pollen eaten. Chewed leaves.	cucumber beetles	Greenish, yellowish beetles 1/4 in long with black spots, black head.
Buds and flowers drop off. Maturing beans pitted, blemished.	lygus bugs	A few can be tolerated.
Blossoms drop off.	hot weather (> 90°F); low soil moisture; smog during blossoming period	Plant early to avoid hot weather during flowering and fruiting period. Do not let soil dry out too much between irrigations.
Poor yield; stunted plants. Roots appear to have knots or beads.	nematodes	Most common in sandy soils. Rotate crops. Soil solarization.
Fluffy, white mycelium growing on leaves, stems, or pods. General rotting. Wilted, water-soaked leaves.	white mold	Caused by a fungus. Increase spacing between plants to improve air circulation. Rotate crops. Remove old plant debris and broadleaf weeds.
Brown spots without yellow halos on leaves and pods; withered leaves.	fungal disease (any of several)	Submit sample for laboratory diagnosis.
Small brown spots surrounded by yellow halos on leaves and pods; withered leaves.	bacterial blight	Avoid overhead watering. Consult UC IPM Pest Notes or Flint 1998 for management options.
Mottled, distorted leaves; leaves may be thickened, brittle, easily broken from plant. Stunted plants. Poor yields.	mosaic virus	Spread from plant to plant by aphids and leafhoppers. Use resistant varieties and remove diseased plants. Remove broadleaf weeds that serve as virus reservoir.
Tiny white grubs inside seed within pod. Circular exit holes may be visible in seed where adult weevils emerged.	bean weevil	Field and storage pest. Remove and destroy bean plants immediately after harvest.
Holes in pods; seed hollowed and eaten.	lycaenid pod borers	Grublike caterpillars that become tiny butterflies as adults. Consult UC IPM Pest Notes or Flint 1998 for management options.
Thin, white, powdery growth on leaves, pods, debris.	powdery mildew	A fungal disease. Use resistant varieties. Spray leaves with strong spray of water. Prune off infected tissue. Rotate plants. Remove old plants. Consult UC IPM Pest Notes or Flint 1998 for management options.
Failure to set pods.	excessive fertilizer or high temperatures; mature pods left on vines	Do not overfertilize. Plant earlier in season before it gets too hot. Pick pods regularly; mature pods cause seed production rather than pod set.

Mung beans, native to India, have enjoyed a rise in popularity because of their use as sprouts in Asian dishes and salads, and gardeners can now find seed available for home production. Mung beans require 90 days of warm weather for good yield in the garden. Garbanzos, or chickpeas, produce plants that do not look like other bean plants. Garbanzos are neither true beans nor peas, but they are leguminous. Their fine-textured foliage is an attractive addition to the garden. Plant many seed; the meaty seed, like limas, tend to rot if they do not germinate and grow rapidly. Each pod also contains only one or two seed. These nutty-flavored beans of unusual texture are good roasted, in salads, and in soups. Garbanzos also require a warm climate and a long (100-day) growing season.

Fava beans, or broad beans, are quite hardy. In cool climates they are often substituted for limas. Favas are sown early in spring or late summer, as they do not grow well in warm weather. It should be noted that some people of Mediterranean origin have a genetic trait (enzyme deficiency) that causes a severe allergic reaction to fava beans. People of this descent should sample the beans in small quantities first.

Beet *(Beta vulgaris)*

Recommended Varieties (Disease resistance, table 13.6)

Ruby Queen (AAS)

Detroit Dark Red

Little Ball (gourmet baby beet)

Early Wonder

Burpee's Golden Beet (for greens and root)

Beets do best in a mild climate, but they grow adequately in warmer climates. However, if temperatures are high when the crop is maturing, some color loss and zoning (internal development of white circles) occur. Temperatures below 50°F for 2 to 3 weeks may cause seed stalks to develop before plant roots mature. In regions where the leafhopper that trans-

Problem Diagnosis for Beets

Problem	Probable cause	Comments
Small, circular spots with light centers and dark borders on leaves.	Cercospora leaf spot	A fungal disease. Pick off and destroy affected leaves.
Cracked roots and black areas on surface and inside roots. Stunted plants.	boron deficiency	Test soil. Maintain pH between 6 and 7. Apply micronutrients.
Leaf margins rolled upward; brittle leaves puckered along veins. Stunted plants.	curly top virus	Spread by beet leafhoppers. Control leafhoppers that spread the virus by practicing weed control.
Misshapen roots.	overcrowding; lumpy, heavy clay soil	Thin beets early.
Cracked roots.	inadequate watering	Maintain adequate soil moisture.
Small holes on leaves.	flea beetle	Control weeds. Consult UC IPM Pest Notes or Flint 1998 for management options.
Scarred or tunneled roots.	root maggot	Destroy infected plants next year. Work in registered insecticide when preparing soil.
Hard, woody beets.	overmaturity; drought	Harvest at proper time. Water consistently.
Tunnels in leaves.	leafminers	Remove infested leaves. Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves webbed together; eggs in rows on undersides of leaves.	beet webworms	Clip off webbed leaves. Destroy caterpillars. Control weeds.

mits the curly top virus is prevalent, plant early to allow the crop to mature before the virus develops. In most sections of California, plant beets in January or February for harvest in the spring. Beets planted in August are ready for harvest by November or December. Thin when the plants are 4 inches tall. At the end of the harvest period, leave roots in the ground and pull them up as desired. Plant roots of 2 inches or less in diameter produce the highest-quality beets.

Broccoli *(Brassica oleracea* var. *italica)*

Recommended Varieties (Disease resistance, table 13.6)

- Green Comet (AAS, H)
- Premium Crop (DM, AAS)
- Green Goliath
- Green Duke
- Emperor (BR, DM, HS)
- Packman

Broccoli matures in 60 to 110 days, depending on the time of year and the variety planted. Late-season varieties (those that overwinter) are not suitable for planting in the home garden. Broccoli grows in most of the cooler areas of the state throughout the year. In the warmer interior valleys, you can grow a fall crop and sometimes an early-spring crop. If temperatures get too high, broccoli will bolt into premature flower stalks that bloom and go to seed.

The immature flower heads, parts of the attached small leaves, and a considerable portion of the stem—4 to 8 inches—are edible. Harvest before the flower buds open. One planting may pro-

Problem Diagnosis for Broccoli

Problem	Probable cause	Comments
Irregular holes in leaves; chewed leaves. Small seedling plants destroyed.	caterpillars (cabbage loopers, armyworms); snails, slugs	*Bacillus thuringiensis* is very effective.
Small holes in leaves; chewed growing points in young plants. Loose cocoons about $^{1}/_{3}$ in long on leaves.	diamondback moth caterpillar	*Bacillus thuringiensis* is very effective. Older plants not damaged. Destroy weeds (mustard type) before planting.
Deformed, curled leaves. Colonies of gray-green insects on leaves. Sticky honeydew.	aphids	Use insecticidal soap spray. Control ants with sticky barrier or insecticide. Encourage beneficials.
Distorted leaves turning plant brown. Wilted plants.	harlequin bug	Insects suck fluids from tissue. Handpick bugs and egg masses. Remove old, nonproductive cole crops (wild radish, mustard) because they're alternate hosts.
Tunnels through roots. Plants fail to grow; may wilt, die. Feeding tunnels in germinating seedlings, which fail to produce plants.	cabbage maggot	Prevent infestation. No practical control when maggots occur on growing crop.
Stunted, wilted plants. Yellowish leaves. Small, glistening white specks on roots.	cyst nematode	Rotate crops. Do not plant cole crops on same site year after year.
Wilted plants. Swollen, misshapen roots; roots rot. Plant dies in later stages.	clubroot	Disease caused by a soilborne fungus. Common in acid soils. Add lime if pH is below 7.2. Rotate out of cole crops for at least 2 years.
Irregular yellowish areas on upper leaf surface; grayish powder on undersides.	downy mildew	Improve air circulation. Plant resistant varieties. Tolerate disease.
Heads suddenly split.	improper watering	Do not allow soil to get too dry. If it gets too dry, apply water slowly at first.
Bolting.	physiological disorder	Plant at right time.
Heads soft and rotten.	bacterial soft rot	Rotate crops. Plant in well-drained soil.
Leaves riddled with shot holes.	flea beetles	Control weeds. Consult UC IPM Pest Notes or Flint 1998 for management options.

duce for as long as 3 months in the late fall or winter because of production from axillary shoots, which produce small heads after the main one is removed.

It is best not to plant brassica crops (e.g., cabbage, broccoli, cauliflower, brussels sprouts, turnips, collard and mustard greens) in the same spot year after year, because diseases and insect pests will build up. Rotate crops in your garden.

Brussels Sprouts *(Brassica oleracea* var. *gemmifera)*

Recommended Varieties (Disease resistance, table 13.6)

Jade Cross (AAS)

Long Island Improved

Royal Marvel

Brussels sprouts grow much better along the coast, where there is a long, cool growing season, than they do in warmer areas. The plants require 80 to 100 days from transplanting until the first sprouts mature. Set out transplants when they are 7 to 8 weeks old. Sprouts form in the axis of each leaf and are clustered around the main erect stem. They can be harvested for a month or more, as the sprouts mature from the bottom of the plant upward. Pick the sprouts when they are green and hard, approximately 1 to 2 inches in diameter, and before the outer leaves turn slightly yellow. Break away the leaf just below the sprout and snap off the sprout. Harvest upward along the stem to the point where the sprouts are too small. Allow these small sprouts to remain on the stem for further development.

It is best not to plant brassica crops (cabbage, broccoli, cauliflower, brussels sprouts, turnips, collard and mustard greens) in the same spot year after year, because diseases and insect pests will build up. Rotate crops within your garden.

Problem Diagnosis for Brussels Sprouts

See "Problem Diagnosis for Broccoli." Many of the cole crops (cabbage, broccoli, cauliflower, and brussels sprouts) suffer from the same diseases, insect pests, and cultural problems. Note for brussels sprouts: If brussels sprouts have loose tufts of leaves instead of firm heads, the sprouts probably developed during weather that was too hot.

Cabbage (*Brassica oleracea* var. *capitata*)

Recommended Varieties (Disease resistance, table 13.6)

Early (< 100 days from time of planting to harvest)

Stonehead (AAS, F)

Early Jersey Wakefield (F)

Golden Acre (F)

Copenhagen Market

Late (> 100 days from time of planting to harvest)

Premium Flat Dutch

Danish Roundhead

Red

Ruby Ball Hybrid (AAS)

Red Head (AAS, F)

Savoy

Savoy Ace (AAS, F)

Savoy King (AAS, BS)

Along the coast, cabbage can be grown year-round. Low temperatures may cause early bolting in young plants. Avoid this problem by planting slow-bolting types or delay planting until the weather warms up. In the interior valleys, cabbage does well when plants mature from late fall to early spring. Plants started in flats are ready for transplanting in about 8 weeks. Harvest when the heads are quite firm and well filled. Some cabbages can be kept reasonably well in the field during cool weather, and they also store well after cutting. Overmature cabbage heads may burst.

It is best not to plant brassica crops (cabbage, broccoli, cauliflower, brussels sprouts, turnips, collard and mustard greens) in the same spot year after year, because diseases and insect pests will build up. Rotate crops within your garden.

Problem Diagnosis for Chinese Cabbage

See "Problem Diagnosis for Cabbage."

Cabbage, Chinese (*Brassica campestris* var. *pekinensis*, heading type; *Brassica chinensis*, bok choy type)

Recommended Varieties (Disease resistance, table 13.6)

Heading, michili type

- Jade Pagoda (B)
- Michili

Heading, Napa type

- China Pride (BSR, DM, TB)

Nonheading, bok choy or pak choi type

- Lei Choi
- Joi Choi
- Pak Choi

Chinese cabbage is extremely sensitive to climate. The crop matures in 80 to 90 days. Flower stalks develop under long-day summer conditions, which usually rules out spring planting unless your garden is located in a cool, coastal climate. Delay planting until mid or late summer so that plants mature in the fall. Plantings made later than summer may not head well because of too much cold weather. The plant grows rapidly and

Problem Diagnosis for Cabbage

Problem	Probable cause	Comments
Deformed, curled leaves; colonies of gray-green insects on leaves. Sticky honeydew.	aphids	Control ants with sticky barrier. Encourage beneficials. Consult UC IPM pest notes or Flint 1998 for management options.
Irregular holes in leaves; chewed leaves. Small seedling plants destroyed.	caterpillars (cabbage loopers, armyworms); snails, slugs	*Bacillus thuringiensis* is very effective.
Tunnels through roots. Plants fail to grow, may wilt, die. Feeding tunnels in germinating seedlings, which fail to produce plants.	cabbage maggot	Prevent infestation. Rotate crops. No practical control when maggots occur on growing crop.
Distorted leaves turning brown. Wilted plants.	harlequin bug	Insects suck fluids from plant tissue. Hand-pick bugs and egg masses. Remove old, nonproductive cole crops (wild radish, mustard) because they're alternate hosts.
Leaves riddled with shot holes.	flea beetles	Control weeds. Consult UC IPM pest notes or Flint 1998 for management options.
Poor heading.	overcrowding; dry soil; root rot	Thin plants early. Irrigate properly. Rotate crops; remove old plant debris.
Stunted, yellowed plants.	poor fertility; dry soil; *Fusarium* fungus	Test soil. Irrigate properly. Use resistant varieties.
Small holes in leaves; loose cocoons about $^1/_3$ in. long on leaves. Chewed growing points in young plants.	diamondback moth caterpillar	*Bacillus thuringiensis* is very effective. Older plants not damaged. Destroy weeds (mustard-type) before planting.
Stunted, wilted plants. Yellowish leaves. Small, glistening white specks on roots.	cyst nematode	Rotate crops. Do not plant cole crops on same site year after year.
Wilted plants. Swollen, misshapen roots; roots rot. Plant dies in later stages.	clubroot	Disease caused by a soilborne fungus. Common in acid soils. Add lime if pH below 7.2. Rotate for at least 2 years.
Head cracking.	excess nitrogen fertilizer; excess water taken up by plant, may be overmature	Fertilize properly. Do not overwater. Harvest heads at maturity.
Heads suddenly split.	improper watering; drought; hot, dry weather followed by excessive water uptake	Do not allow soil to get too dry. If it gets too dry, apply water slowly at first. Prune roots to reduce water uptake and slow growth.
Bolting.	physiological disorder	Plant at right time of year. Some varieties are resistant.
Heads soft and rotten.	bacterial soft rot	Rotate crops; plant in well-drained soil. Use resistant variety.

yields well. Harvest heading types when the cabbage is well headed and firm.

Cantaloupe, Muskmelon, and Honeydew *(Cucumis melo)*

Recommended Varieties (Disease resistance, table 13.6)

Orangeflesh

- Samson (AAS, F, PM)
- Ambrosia (DM, PM)
- Saticoy Hybrid (F, M, PM)
- Topmark (PM)
- Bush Star (bush plant) (AAS, F, PM)
- Honeybush (bush plant) (F)
- Crenshaw
- Casaba
- Galia
- Rocky Sweet

Honeydew

- Tam Dew (fruit slips when mature) (DM, PM)
- Earlidew (F)
- Fruit Punch (distinctive flavor)
- Limelight (F)

The term *cantaloupe* refers to certain varieties of muskmelon *(Cucumis melo)*; cantaloupes are often called muskmelons and vice versa. Honeydew melons are also types of muskmelons. Cantaloupe, honeydew melon, cucumber, squash, pumpkin, and watermelon belong to the Cucurbitaceae, the gourd or cucurbit family. Cucurbits suffer from similar pests and diseases. It is best to rotate these related crops so that a portion of the garden is free from them periodically. See "Fruit Set Problems in Squash, Melons, and Cucumbers," in the squash section, below. Melons require high temperatures during the growing season and therefore do best in warm interior valleys. Most varieties require 90 days to produce fruit.

Vines have separate male and female flowers, and bees are required for pollination. To prevent killing bees, use insecticides late in the evening, if at all. Male blooms form first and do not set fruit; thus, do not be concerned when male flowers fall off. A heavy rain when melons are ripening may cause some of the fruit to split open. Fruit in contact with soil may develop rotten spots or be damaged by insects on the bottom. Place a board or a few inches of mulching material, such as sawdust or straw, beneath each fruit when it is nearly full size.

Harvest melons when the fruit is at full slip, that is, when a slight crack completely circles the stem where it is attached to the fruit. If you harvest at the right time, you can pull off the stem, leaving a smooth cavity. However, the slip does not develop in crenshaw, casaba, or some honeydew varieties. Harvest these melons when the fruit softens at the blossom end and starts to turn yellow. Shade crenshaw fruit to protect them from sunburn. Melons may only be stored for a short time, except casaba and honeydew, which store well for several weeks.

Carrot *(Daucus carota)*

Recommended Varieties (Disease resistance, table 13.6)

Baby or gourmet (3–5 in; good in containers or garden)

- Short 'n Sweet
- Little Finger
- Amstel
- Kundulus, round
- Lady Finger
- Amsterdam

Problem Diagnosis for Cantaloupe

Problem	Probable cause	Comments
Deformed, curled leaves; small, soft-bodied insects on undersides of leaves. Sticky honeydew or black, sooty mold may be present.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Fine stippling on leaves; yellow or brown leaves. Leaf undersides are silver-gray with fine webbing and yellow, orange, or red dots.	spider mites	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves turn yellow. Honeydew or sooty mold present. Clouds of tiny white insects fly up when plant is disturbed.	whiteflies	Remove infested plants as quickly as possible. Remove lower, infested leaves of plants not totally infested.
Coarse, white stippling on upper surface of leaves; leaves may turn brown.	leafhoppers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Blotches or tunnels on leaves.	leafminers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Angular necrotic areas on leaves.	angular leaf spot	Caused by waterborne bacterium. Avoid wetting foliage with irrigation water.
Swelling or beads on roots. Wilted plants. Poor yields.	nematodes	Rotate crops. Use soil solarization.
Holes chewed in leaves. Scarring of runners, young fruit, and crown. Wilting. Beetles are visible.	cucumber beetles	Beetles are yellow-green with black stripes or spots. Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves have small specks that turn yellow, then brown. Vines wilt from point of attack to end of vine.	squash bug	Trap adults beneath boards in spring. Turn over boards in morning and kill bugs. Pick off adults, young, egg masses.
White, powdery spots on leaves and stems. Spots may enlarge and completely cover leaf. Defoliation may occur. Yields reduced.	powdery mildew	Spores of powdery mildew fungus are spread by wind and air currents. Disease is less severe in hot, dry weather. Use resistant varieties. Remove old plant debris. Consult UC IPM Pest Notes or Flint 1998 for management options.
Yellow spots on upper leaf surfaces. Grayish, fuzzy growth on undersides of spots.	downy mildew	A fungal disease. Use resistant varieties. Remove old plant debris.
Stunted plants. Small leaves with irregularly shaped light and dark spots (mottled). Yields reduced.	mosaic virus	Transmitted by aphids. Use resistant varieties and remove infected plants as soon as detected. Control aphids. Control weeds. Aluminum foil is effective as soil mulch to reduce infection. Deformed fruit is edible.
Poor fruit set.	insufficient pollination; lack of bee pollinators	Hand-pollinate using artist's paintbrush. Bee activity may be low because of cool weather or insecticides.
Misshapen or bitter fruit.	inadequate pollination; dry soil or high temperatures; poor soil fertility	See comments above. Supply water. Get soil tested.
Poor flavor. Lack of sweetness.	poor soil fertility; low potassium, magnesium, or boron	Get soil tested and adjust fertilizer.
Plants wilt and die, beginning with older crown leaves. Light brown streaks occur inside lower stem, runners, and root—visible when split lengthwise.	Verticillium wilt	Caused by soilborne fungus. Rotate crops. Avoid soil previously planted in potatoes, peppers, eggplant, tomatoes, or cucurbits.
Plants wilt suddenly. Roots rot.	sudden wilt	Fungal disease. Avoid water stress after fruit set. Avoid wetting soil to the crown. Improve drainage. Plant on raised beds.
Runners turn yellow and wilt. Entire plant collapses. One-sided brown lesion may form on affected runner for 1–2 ft.	Fusarium wilt	Caused by soilborne fungus. Plant resistant varieties. Rotate out of cantaloupe for 5 years.
Water-soaked and sunken, brown or black spots on fruit not restricted to blossom end.	belly rot	Rotate crops. Improve drainage. Stake or cage to keep fruit off ground.
Water-soaked, sunken, brown or black spot at blossom end of fruit.	blossom end rot	Water during dry periods; keep soil moisture even; remove affected fruit.
Excessive vegetative growth.	planting too close together	Increase plant spacing.

Minicor

Elevated vitamin A

A-Plus Hybrid (8 in, tapered)

Vitasweet group

Long, tapered (7–10 in; requires deep soil)

Gold Pak 28 (AAS, C)

Imperator

Danvers

Medium long (5–6 in; for shallower soil)

Nantes

Chantenay (A, C)

Danvers

Carrot seed germinate best under cool, moist conditions in the spring, but they may be started in slightly warmer weather if the soil is kept moist. Use or prepare soil that is deep and friable to avoid misshapen roots. Do not plant in areas where young plants may be subject to long periods of cold temperatures, which favors bolting. Thin so that plant roots are 1 to 2 inches apart in the row.

Carrots are ready to harvest about 90 days after seeding but continue to grow and enlarge thereafter. Harvest when the roots are of good size but still tender. Carrots may be stored in the ground during cool winter months unless freezes are

Problem Diagnosis for Carrot

Problem	Probable cause	Comments
Carrots fail to emerge.	soil crusting; high soil temperatures; seedling pests	Maintain uniform soil moisture until seedlings emerge. Protect soil surface from rain or sprinklers. Do not plant too deeply.
Thin, spindly growth.	weed competition	Control weeds.
White growth on leaves.	powdery mildew	Consult UC IPM Pest Notes or Flint 1998 for management options.
Carrots twist around each other.	plants too close together	Thin carrots to 1–2 in apart when plants are small.
Carrots rot or have enlarged white "eyes."	overwatering	Water less often. Do not plant carrots in heavy soil.
Rotten roots. White fungus growth on soil surface and clinging to roots. Small, oval honey-colored to brown sclerotia in fungal growth.	southern blight or white mold	Caused by a fungus. Avoid planting in infested soil. Nitrogen fertilizers may help.
Roots have surface tunnels filled with rusty mush. Stiff, white maggots may be visible, but no aboveground symptoms.	carrot rust fly	A small fly that lays its eggs in crowns of carrots. Control weed hosts. Peel off damaged area before using. Harvest carrots as soon as possible. Do not store carrots in ground through winter.
Roots hairy, forked, misshapen.	root knot nematode; overwatering; roots in contact with fertilizer pellets or fresh manure; hard soil or rocks; overcrowding	Rotate crops. Use soil solarization. Remove rocks in soil. Thin carrots early.
Yellowed, curled leaves. Stunted plants.	leafhoppers	Consult UC IPM Pest Notes or Flint 1998 for management options..
Brown spots on leaves or roots.	leaf blight	Avoid planting in infested soil. Nitrogen fertilizer may help.
Tiny holes on leaves.	flea beetles	Control weeds. Consult UC IPM Pest Notes or Flint 1998 for management options.
Inner leaves yellowed; outer leaves reddish purple. Roots stunted and bitter.	aster yellows	A mycoplasma disease. Remove affected plants. Control weeds. Control leafhoppers. Consult UC IPM Pest Notes or Flint 1998 for management options.
Green root tops.	roots exposed to sunlight	Cover exposed roots with soil or mulch.

expected. If frosts are predicted, dig up and store the carrots. If carrots are left too long in the soil or allowed to overmature, the roots become tough, woody, and may crack.

Cauliflower *(Brassica oleracea* var. *botrytis)*

Recommended Varieties (Disease resistance, table 13.6)

Snow King (AAS)

Snowball Y

Snow Crown (AAS)

There are many Snow and Snowball cauliflower selections from which to choose; Snowball Y is usually the most successful. Snowball A is an early producer. Cauliflower grows best in cool, fairly moist climates. Plants are ready for transplanting 8 weeks after seeding; the crop can also be direct-seeded in the garden. Snowball may be grown as both a fall and spring crop and can produce

Problem Diagnosis for Cauliflower

Problem	Probable cause	Comments
Irregular holes in leaves; chewed leaves. Small seedling plants destroyed.	caterpillars (cabbage loopers, armyworms); snails, slugs	*Bacillus thuringiensis* is very effective.
Small holes in leaves. Chewed growing points in young plants. Loose cocoons about 1/3 in long on leaves.	diamondback moth caterpillar	*Bacillus thuringiensis* is very effective. Older plants not damaged. Destroy weeds (mustard type) before planting.
Deformed, curled leaves. Colonies of gray-green insects on leaves. Sticky honeydew.	aphids	Control ants with sticky barrier. Encourage beneficials. Consult UC IPM Pest Notes or Flint 1998 for management options.
Distorted leaves turning brown. Wilted plants.	harlequin bug	Insects suck fluids from plant tissue. Handpick bugs and egg masses. Remove old, nonproductive cole crops (wild radish, mustard) because they're alternate hosts.
Tunnels through roots. Plants fail to grow, may wilt, die. Feeding tunnels in germinating seedlings, which fail to produce plants.	cabbage maggot	Prevent infestation. No practical control when maggots occur on growing crop.
Leaves riddled with shot holes.	flea beetles	Control weeds. Consult UC IPM Pest Notes or Flint 1998 for management options.
Stunted, wilted plants. Leaves yellowish. Small, glistening white specks on roots.	cyst nematode	Rotate crops. Do not plant cole crops on same site year after year.
Wilted plants. Swollen, misshapen roots. Roots rot; plant dies in later stages.	clubroot	Disease caused by a soilborne fungus. Common in acid soils. Add lime if pH is below 7.2. Rotate for at least 2 years.
Irregular, yellowish areas on upper leaf surface; grayish powder on undersides.	downy mildew	Improve air circulation. Plant resistant varieties. Tolerate it.
Poor heading.	overcrowding; dry soil; root rot	Thin plants early. Irrigate properly. Rotate; remove old plant debris.
Heads yellow or brown instead of white.	sunburn	When head is 3 in in diameter, tie outer leaves around head with twine. Harvest in 4 to 7 days.
Head cracking; leaves may grow through head.	excess nitrogen fertilizer; hot, dry weather, overmature	Fertilize properly. Plant so crop develops in mild or cool weather. Do not let soil dry out.
Heads suddenly split.	sudden, heavy watering after prolonged dry period	Do not allow soil to get too dry. If it gets too dry, apply water slowly at first. Prune roots to reduce water uptake and slow growth.
Bolting.	physiological disorder	Plant at right time.
Heads soft and rotten.	bacterial soft rot	Rotate crops; plant in well-drained soil.

good heads within 2 months after transplanting. Late varieties require 4 to 6 months and are not recommended for planting in most home gardens.

Avoid any condition that may check plant growth. Adequate moisture is essential. Good vegetative growth is very important for subsequent growth of the cauliflower head. Interference with rapid, uniform growth may cause premature development of the head. Such heads are smaller than usual. Cauliflower is the cole crop most sensitive to temperature. Stresses such as cold soil or air temperatures in the spring, lack of fertility, water stress, insect damage, disease, and using transplants with poor root growth or that are root-bound before transplanting can result in a condition known as buttoning. Varieties that mature a short time after transplanting are more susceptible to stress than are varieties that require a longer period to mature. Properly grown transplants, adequate fertility, regular irrigation, and good insect and disease control help ensure a successful crop. Premature heading in cauliflower is more frequent in home gardens than in commercial plantings.

As the heads enlarge, they may become exposed to the sun and discolor. Avoid this by folding the leaves over the heads or by tying the leaves together to protect the developing curd from the sun. Harvest when the heads are of good size, usually 5 to 6 inches in diameter, and are still compact. As the heads become overmature, they tend to segment or spread apart, and the surface becomes fuzzy.

It is best not to plant brassica crops (cabbage, broccoli, cauliflower, brussels sprouts, turnips, collard and mustard greens) in the same spot year after year, because diseases and insect pests will build up. Rotate crops within your garden.

Problem Diagnosis for Celeriac

See "Problem Diagnosis for Celery."

Celeriac *(Apium graviolens* var. *rapaceum)*

Recommended Varieties

- Alabaster
- Marble Ball
- Large Smooth Prague

Celeriac is often called celery root because the enlarged, bulbous root is the edible part of the plant. It tastes like mild celery. Follow the same cultural procedures as for growing celery. The crop is usually direct-seeded; transplants often produce poorly shaped roots. Harvest when the roots are 3 to 5 inches in diameter. You can then peel the roots and use them raw or cooked in salads, soups, and stews.

Celery *(Apium graviolens* var. *dulce)*

Recommended Varieties (Disease resistance, table 13.6)

- Giant Pascal (BR)
- Tall Utah 52-70
- Golden Self-Blanching (waxy yellow petioles)
- Matador

Celery is usually produced from transplants; use transplants that are 10 to 12 weeks old. If you grow it from seed, place a shallow covering of soil over the seed and keep the soil quite moist. Do not seed when temperatures are high; heat induces seed dormancy, and the seed do not germinate. Celery is a cool-season crop that grows best with temperatures at 60° to 65°F, and it requires ample water and nitrogen fertilizer.

The crop is ready to cut 90 to 120 days after transplanting. Harvest by cutting below the ground through the taproot. The edible portion is the fleshy leaf petiole. If long periods of cool temperatures occur during growth, seed stalk development may occur. Overmature plants show cracking and pithiness of the petioles.

Chard *(Beta vulgaris* var. *cicla)*

Recommended Varieties

- Argentata
- Fordhook Giant
- Lucullus
- Rhubarb Chard (red leaf, stems)
- Rainbow

Problem Diagnosis for Celery

Problem	Probable cause	Comments
Poor growth; stunted plants.	crop not well adapted to many areas of California	Time planting so that crop matures during cool season. Plant recommended variety.
Tough, bitter stalks.	high temperatures; dry soil; poor fertility; overmaturity	Plant at proper time. Celery requires lots of water and high nitrogen. Harvest when tender.
Blotches or tunnels in leaves.	leafminers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Brown or gray spots on leaves and stalks.	fungal leaf spot	Consult UC IPM Pest Notes or Flint 1998 for management options.
Bolting.	physiological disorder	Plant recommended varieties. Plant at right time.
Twisted, brittle stalks. Stunted, yellowed plants.	aster yellows	A mycoplasma disease. Remove infected plants. Control weeds. Control leafhopper vectors with insecticide.
Heart of plant may be black.	calcium deficiency; improper soil pH	Test soil. Maintain pH between 6.5–8.0. Water during dry periods. Calcium deficiency can be due to uneven water supply.
Wilted plants; soft, watery rot on leaves and stalks.	fungal crown rot	Rotate crops. Remove old plant debris. Consult UC IPM Pest Notes or Flint 1998 for management options.

Problem Diagnosis for Chard

See table 13.5 for general techniques for recognizing and managing the common problems associated with chard. Because beets are one of chard's close relatives, also see "Problem Diagnosis for Beet." Common disease problems in chard include curly top virus and nematodes. Common insect pests that attack chard include aphids, cabbage worm, flea beetles, and leafminers.

Bright Lights

Chard is often called Swiss chard in vegetable gardening books. Chard requires the same care as beets, one of its close relatives, although chard is grown for its succulent stalks and flavorful leaves. In nondesert areas, plant seed in late winter or early spring to avoid severe damage from curly top virus. Plants bear heavily and produce greens for most of the year. The leaves can be cooked or used fresh in salads. Chard is easy to grow and ready for harvest in 50 to 60 days. Harvest by cutting or breaking away a few of the outer, fully expanded leaves from each plant near the base. New leaves develop in the center of the plants as the older ones are cut away. You can harvest from one plant numerous times. If you do not harvest the outer leaves, they become stringy and lose tenderness.

Chayote *(Sechium edule)*

Recommended Varieties

No named varieties are available.

The chayote, native to Central America, looks like a mango-shaped squash and tastes like a mild squash. Chayote is a vigorous, perennial subtropical vine similar in growth habit to cucumber. It requires a long, warm growing season and can be grown in warm coastal areas for fall and early winter harvest. Chayote has the unique botanical characteristic of vivipary, in which the seed embryo can germinate while inside the fruit and the fruit is on the plant. Vivipary can be undesirable for fruit handling and use, but it is useful in propagating plants.

There are no commercial sources of propagation material. Fruit purchased in a grocery store or provided by a fellow gardener usually produce plants. Plant whole fruit in warm soil in the spring. Place them on a 45° angle in the soil with the stem end up and slightly protruding through the soil surface. Train the vines on a sturdy trellis. Chayote grows best if soil is maintained uniformly moist. It needs modest fertilizer; excessive nitrogen will reduce or delay flowering and fruit production. The flowers appear in late summer to early fall, and the first fruit matures about 30 days later.

Harvest fruit as soon as the fruit are

Problem Diagnosis for Chayote

See table 13.5 for general techniques for recognizing and managing the common problems associated with chayote. Common pathogens that attack chayote include powdery mildew and nematodes. Common insect pests that attack chayote include aphids, cucumber beetles, mites, squash bug, and squash vine borer.

Problem Diagnosis for Chives

See table 13.5 for general techniques for recognizing and managing common problems associated with chives. Because chives are relatives of onions and garlic, they suffer from similar pest insects, diseases, and cultural problems. Also see "Problem Diagnosis for Onion."

full grown (4–6 in long). Fruit may be smooth, bristly, green, or white, depending on the selection grown.

Chives *(Allium schoenoprasum)*

Recommended Varieties

No named varieties are available.

Grow chives from seed or by dividing an already established plant. Chives are extremely suitable for growing in small pots or other minigardens. A minimum of 4 to 6 inches of soil and a pot diameter of 6 to 8 inches is recommended. Chives give a mild onion flavor to salads and other dishes. They are relatives of onions, garlic, and leeks, which are all members of the *Allium* genus.

Corn, Ornamental, Specialty, and Sweet *(Zea mays)*

Recommended Specialty Varieties

Baby (harvest baby corn when silks first appear and ears are quite small)

Baby Asian and other white sweet corn

Ornamental

Rainbow

Strawberry Popcorn

Blue Tortilla

Indian Fingers (small, multicolored ears, shiny kernels)

Papoose (small, multicolored ears)

Ornamental Indian Corn

Squaw

Popcorn

Golden Hybrid (yellow)

White Cloud (white)

Black Popcorn (black kernel with white interior)

Peppy Hybrid (white)

Recommended Sweet Varieties (Disease resistance, table 13.6)

Standard sugary

Golden Cross Bantam (yellow) (BW)

Jubilee (yellow) (SG, ST)

Butter and Sugar (bicolor) (BW, SCLB)

Silver Queen (white) (BW, SW)

Sugary enhanced

How Sweet It Is (white) (AAS)

Breeder's Choice (light yellow)

Kandy Korn (yellow)

Concord (bicolor)

Supersweet

Early Xtra Sweet (yellow) (AAS)

Ivory 'n Gold Bicolor (bicolor)

Butterfruit (yellow)

Sweetie (yellow)

Illini Gold (yellow)

Butterfruit Bi-color (bicolor)

Escalade (bicolor)

Supersweet Jubilee (yellow)

Maxim (yellow)

There are three types of sweet corn varieties: standard sugary, sugary enhanced, and supersweet. Standard sugary types are older varieties that lose sweetness quickly because sugar in the kernels converts rapidly to starch after harvest. Sugary enhanced and supersweet types possess genes that increase sweetness and, in supersweet types, slow the conversion of sugar to starch after harvest. Supersweet types do not lose sweetness after harvest as quickly as do the other two types. Some supersweet types are less creamy than standard or sugary enhanced types, which may decrease their suitability for canning or freezing.

Sweet corn varieties also differ significantly in time to maturity and may be yellow, white, or bicolor. Most varieties are hybrids that have been bred for greater vigor and higher yields in addition to sweetness. A continuous harvest can be planned by planting early-, mid-, and late-season varieties or by making successive plantings of the same variety every 2 weeks or when the last planting has three or four leaves (corn sown in early spring takes longer because of cool temperatures). Use only the earliest varieties for late-summer or early-fall plantings to ensure a good fall crop. Fall-maturing

sweet corn is almost always the highest quality, because cool nights in fall increase sugar content. Sweet corn grows well in warm climates, but if temperatures are too hot, ears may fail to fill out normally.

Pollination is a very important consideration in planting sweet corn. Because corn is wind pollinated, block plantings of at least three or four short rows are pollinated more successfully than one or two

Problem Diagnosis for Corn

Problem	Probable cause	Comments
Young plants chewed off at ground level.	cutworms	Remove weeds. Destroy crop residues.
Distorted leaves or stalks. Stalks may be bent or leaves may fail to unfurl.	herbicide injury; cold weather; aphids	Use herbicides carefully. Plant at proper time. Consult UC IPM Pest Notes or Flint 1998 for aphid management options.
Worms up to 1¾ in long eat down through kernels. Before tasseling, worms found in whorl of plant feeding on developing tassel.	corn earworm	Worms range in color from green to black with lengthwise stripes of various colors. Apply mineral oil with medicine dropper to silk just inside the ear tip 3–7 days after silks first appear. Use 20 drops/ear. Break off wormy end of ear and discard. Insecticides will not control worms inside ear. Preventive treatment of silks (above) kills worms before they enter ears.
Holes in leaves.	armyworm; corn earworm; various beetles; grasshoppers	Ignore or handpick insects. Loss of small amount of leaf tissue will not reduce yields.
Sticky, shiny leaves. Stunted plants. Insects visible.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Mottled leaves; leaves die along margins. Slow growth.	mosaic virus	No control; certain varieties are more resistant.
Ears, tassels, leaves have gray, gnarled growths (galls) that become powdery.	common smut	Caused by a fungus. Remove and destroy galls as soon as found. Keep black powder in galls from getting into soil. Plant resistant varieties. Plant early. Problem is more common in later harvests.
Brown spots (pustules) on leaves with powdery, rust-colored spores.	rust	Caused by a fungus. Plant resistant varieties. Favored by cool temperatures, high humidity, overhead sprinklers. Consult UC IPM Pest Notes or Flint 1998 for management options.
Incomplete kernel development; shriveled kernels.	poor pollination	Can be caused by not planting enough corn at one time. Plant at least 3–4 rows at least 8 ft long.
	insufficient soil moisture	Supply enough water, especially from silking to harvest.
	hot weather, high winds 2–3 weeks before harvest	
	inadequate fertilizer	Fertilize as directed. Check for potassium deficiency. Plant varieties adapted to your area.
	birds	Put paper bag over ear after pollination.
Ears only partly filled. Shortened silks.	earwigs	Earwigs feed on silks and prevent pollination, killing kernels. Use traps. Check daily for earwigs and destroy.
Brown lesions on stalks near joints; stalks rotten inside. Kernels pink or moldy.	stalk and ear rot	Caused by several fungi. Remove old plant debris. Maintain uniform soil moisture.
Stunted plants with yellow-green stripe or mosaic pattern; older leaves pale yellow.	maize dwarf mosaic virus	Control weeds, esp. johnsongrass. Control aphids. Destroy affected plants. Do not handle healthy plants after infected ones. Plant resistant varieties.
Lodging (plants falling over).	excess nitrogen fertilizer	Test soil. Adjust fertilization.

long rows. Good pollination is essential for full kernel development. Most types of corn cross-pollinate readily. To maintain desirable characteristics and high quality, be certain that supersweet types are isolated from standard sugary and sugary enhanced types, since cross-pollination results in supersweet ears with tough, starchy kernels. Grow only one supersweet variety or schedule plantings of different sweet corn types so that maturity dates are 1 month apart to ensure isolation. Sweet corn plantings must also be isolated from field corn, popcorn, and ornamental corn. If the two previous isolation methods are not feasible, isolation can be attained by establishing a distance of 400 yards between plantings of different corn types. White and yellow types also cross-pollinate, but the results are not as problematic.

Some gardeners are interested in growing baby corn, such as that found in salad bars and gourmet sections of grocery stores. Baby corn is immature corn, and many varieties are suitable, but Baby Asian, with its small-diameter cob at maturity, is good to try. Harvesting at the right time is tricky; harvest when silks first appear but ears are not filled out. Experimentation is the best way to determine when to harvest baby corn.

It is not necessary to remove suckers or side shoots that form on sweet corn. With adequate fertility, these suckers may increase yield, and removing them has been shown in some cases to actually decrease yield.

Mulching is a useful practice in growing corn because adequate moisture is required from pollination to harvest to guarantee that ears are well filled. Mulching reduces evaporation of soil moisture and keeps the moisture content of the soil fairly constant. Most organic mulches are suitable; newspaper held down with a heavier material on top is an excellent moisture conserver in corn.

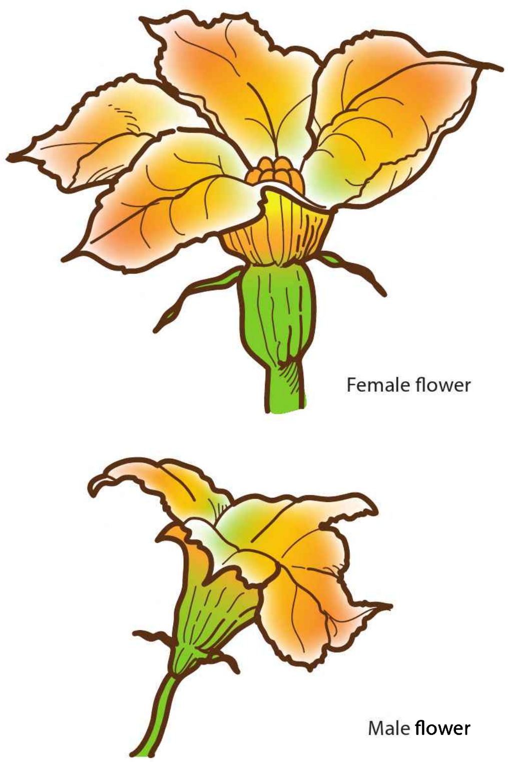
Normally, sweet corn is ready for harvest about 17 to 24 days after the first silk strands appear, more quickly in hot weather and more slowly in cool weather. Harvest corn at the “milk stage,” when husks are still green, silks are dry brown, and kernels are full sized and yellow or white to the tip of the ear. Use your thumbnail to puncture a kernel. If the liquid is clear, the corn is immature; if the kernel is plump and the liquid is milky, it is ready to be picked; if there is no sap, it is too late. Cover unharvested ears checked by this method with a paper bag to prevent insect or bird damage. Experienced gardeners can feel the outside of the husk and tell when the cob has filled out and is ready to harvest.

If corn is to be stored for a day or two, pick it in the cool temperatures of early morning to prevent the ears from building up an excess of field heat, which causes more rapid conversion of sugars to starch. The best time to pick corn is just before eating it; some cooks say to have the pot of water coming to a boil as you are picking the corn and husk it on the way from the garden to the house! This may be an exaggeration, but with standard varieties, the conversion of sugar to starch is rather rapid. Field heat can be removed from ears picked when temperatures are high by plunging the ears in cold water or putting them on ice for a short time. Harvested ears of all varieties of sweet corn should be stored as cold as possible in the refrigerator until ready to use. Supersweet varieties benefit from this treatment, but they are not as finicky because they have a higher sugar content and hold their sweetness longer.

The most serious pest of sweet corn is usually the corn earworm, which eats down through the kernels of ears. It can be difficult to control, although early plantings of corn are sometimes less affected by this pest.

Figure 13.3

Cucumber flowers. *Source:* After Johnson 1981, p. 2.



Cucumber *(Cucumis sativus)*

Recommended Varieties (Disease resistance, table 13.6)

Pickling

- Liberty Hybrid (AAS, ALS, DM, M, PM, S)
- Saladin (AAS, DM, CMV, PM)
- County Fair 83 (AN, DM, M, PM, S)
- Pickle Bush (compact, suitable for containers) (CMV, PM)
- Pot Luck (container only) (CMV)

Slicing

- Dasher II (CMV, DM, PM, S)
- Sweet Success (AAS, AN, ALS, CMV, DM, PM, S)
- Sweet Slice (burpless) (AN, CMV, DM, S, PM)
- Burpee Hybrid (DM, M)
- Bush Champion (suitable for containers) (M)
- Parks Bush Whopper (container)
- Pot Luck (container only) (CMV)
- Salad Bush (suitable for containers)
- Spacemaster (bush, suitable for containers) (M)
- Slice Nice (AN, DM, S)
- Slice Master Hybrid (ALS, AN, DM, M, PM, S)

Varieties of cucumber include the slicing, or fresh salad, type; the pickling type, which can also be used fresh; and the standard dwarf-vined or bush varieties. Cucumbers are generally monoecious; that is, they bear separate male and female flowers on the same plant. On a normal cucumber plant, the first 10 to 20 flowers are male, and for every female flower, which will produce the fruit, 10 to 20 male flowers are produced. These facts indicated to plant breeders that production could be increased greatly if many more female flowers were produced. Some of the new varieties produce plants that have a greater proportion of female to male flowers, and others, called gynoecious types, have only female flowers. These plants tend to bear fruit earlier, with a more concentrated set and better yields overall.

In order for the flower to develop into a fruit, pollen must be carried by bees from male flowers on the same plant or on different plants to the female flower, the one with the tiny swollen pickle (fig. 13.3). Gynoecious (female) cucumber flowers are pollinated by male flowers from other plants, the seed of which are usually included in the seed packet. Poor cucumber set is common during rainy weather, when bees are inactive (see the sidebar "Fruit Set Problems in Squash, Melons, and Cucumbers" in the squash section, below). If pesticides are needed, use them late in the afternoon to avoid harming the bee population.

Some varieties of cucumbers are parthenocarpic; that is, the female flowers produce fruit without being pollinated. The cucumbers from these plants are seedless. This type is usually grown in

Bitterness in Cucumbers

Each year, some home gardeners experience bitterness in cucumbers that they have grown for fresh use or pickling. Bitterness is due to the formation of two cucurbitacins (terpenoid compounds) that impart a bitter flavor to seedlings, roots, stems, leaves, and fruit (see Pittenger 1983). Two genes are involved in controlling bitterness in cucumber: a dominant gene produces extremely bitter fruit, and a recessive gene inhibits the formation of curcurbitacin in foliage and fruit. An enzyme, elaterase, hydrolyzes cucurbitacins to nonbitter compounds. Elaterase activity is believed to be controlled independently of the genes controlling bitterness.

Usually the bitter cucurbitacin does not accumulate very heavily in the fruit. When it does, it accumulates nonuniformly among fruit and within a fruit. Cucurbitacins are likely to concentrate at the stem end and in and just under the fruit skin.

The amount of bitterness in cucumbers appears to vary from year to year and from location to location. This may occur because elaterase production is stimulated or depressed under certain environmental conditions. Cool temperatures can enhance bitterness; fertilization, plant spacing, and irrigation frequency have exhibited little consistent effect on the number of bitter cucumbers produced. Also, varieties vary widely in their tendency to be bitter.

Avoid growing cucumbers in cool or shaded locations and provide uniform moisture and ample nutrients to ensure a good yield of quality fruit. Select the new hybrid varieties, as they seem to have less of a tendency toward bitterness. If a fruit expresses bitterness, it can usually be eliminated by peeling away the skin and outer flesh and removing the stem end. The direction of peeling does not have an effect on the spread of bitterness.

greenhouses; if it is planted near other varieties, pollination can occur and the fruit can have seeds.

Burpless cucumbers are long and slender with a tender skin. Through plant breeding, the bitterness associated with the burp has been removed. Environmental causes of bitterness in cucumbers include temperature variation of more than 20 degrees, shaded conditions, and moisture stress.

Most varieties of cucumber vines spread from row to row. Training on a cage, trellis, or fence along the edge of the garden will correct this and also lift the fruit off the soil. Trellising also gets leaves off the ground so that they dry off faster. Trellised vines are less likely to be stepped on or damaged during weeding. If trellising is not possible, many excellent bush cucumber varieties are available. Most of them produce well for a limited amount of space and may be a desirable alternative in a small garden. If vines are not trellised, avoid destroying blossoms or kinking vines by gently rolling the vines away rather than lifting them when searching for harvestable fruit. In nontrellised plantings, organic mulches are useful to maintain soil moisture and keep the fruit clean.

Working in the vines when leaves are wet can spread disease. Wait until after morning dew or rain evaporates. There has been a significant increase in disease resistance in cucumber varieties in recent years. Select resistant varieties when possible.

Harvest cucumbers when they are from 2 inches to 8 to 10 inches long, but be sure to harvest before they begin to turn yellow. Remove fruit by turning cucumbers parallel to the vine and giving a quick snap to prevent vine damage and make a clean break.

Eggplant *(Solanum melongena)*

Recommended Varieties (Disease resistance, table 13.6)

Black Beauty

Problem Diagnosis for Cucumber

Problem	Probable cause	Comments
Deformed, curled leaves. Small, soft-bodied insects on undersides of leaves. Sticky honeydew or black, sooty mold may be present.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Fine stippling on leaves; yellow or brown leaves; leaf undersides silver-gray with fine webbing and yellow, orange, or red dots.	spider mites	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves turn yellow. Honeydew or sooty mold present. Clouds of tiny white insects fly up when plant is disturbed.	whiteflies	Remove infested plants as quickly as possible. Remove lower, infested leaves of plants not totally infested.
Coarse, white stippling on upper surface of leaves. Leaves may turn brown.	leafhoppers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Blotches or tunnels on leaves.	leafminers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Angular necrotic areas on leaves.	angular leafspot	Caused by waterborne bacterium. Avoid wetting foliage with irrigation water. Use resistant variety.
Swelling, beads on roots. Wilted plants. Poor yields.	nematodes	Rotate crops. Use soil solarization.
Holes chewed in leaves. Scarring of runners, young fruit. Wilting. Beetles visible.	cucumber beetles	Beetles are yellow-green with black stripes or spots. Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves have small specks that turn yellow, then brown. Vines wilt from point of attack to end of vine.	squash bug	Trap adults beneath boards in spring. Turn over boards in morning and kill bugs. Pick off adults, young, egg masses.
White, powdery spots on leaves and stems. Spots may enlarge and completely cover leaf. Defoliation may occur. Yields reduced.	powdery mildew	Spores of powdery mildew fungus are spread by wind and air currents. Disease is less severe in hot, dry weather. Plant resistant varieties. Remove old plant debris. Consult UC IPM Pest Notes or Flint 1998 for management options.
Yellow spots on upper leaf surfaces. Grayish, fuzzy growth on undersides of spots.	downy mildew	Caused by a fungus. Plant resistant varieties. Remove old plant debris.
Stunted plants, small leaves with irregularly shaped light and dark spots (mottled). Yields reduced.	mosaic virus	Transmitted by aphids. Remove infected plants as soon as detected. Plant resistant varieties. Control aphids. Control weeds. Aluminum foil is effective as soil mulch to reduce infection. Deformed fruit is edible.
Poor fruit set.	insufficient pollination; lack of bee pollinators	Hand-pollinate using artist's paintbrush if bee pollinators are too few. Bee activity may be low due to cool weather or insecticides.
Bitter fruit.	cucurbitacin compounds	See text for discussion and recommendations.
Plants wilt and die, beginning with older crown leaves. Light brown streaks occur inside lower stem, runners, and root—visible when split lengthwise.	Verticillium wilt	Caused by soilborne fungus. Rotate crops. Avoid soil previously planted in potatoes, peppers, eggplant, tomatoes, or cucurbits.
Plants wilt suddenly. Roots rot.	sudden wilt	Caused by fungus. Avoid water stress after fruit set. Avoid wetting soil to the crown. Improve drainage. Plant on raised beds.
Water-soaked, sunken, brown or black spot on fruit not restricted to blossom end.	belly rot	Rotate crops. Improve drainage. Stake or cage to keep fruit off ground.
Excessive vegetative growth.	planting too close together	Increase plant spacing.

Note: Cucumbers *(Cucumis sativus)* are relatives of melons *(Cucumis melo)*, including cantaloupe, honeydew, and crenshaw; winter and summer squash *(Cucurbita pepo* var. *melopepo)*; pumpkin *(Cucurbita pepo* var. *pepo)*; and watermelon *(Citrullus lanatus)*. Known collectively as cucurbits, they suffer from similar pests and diseases, as evident from the problem diagnosis table.

Epic (TMV)

Early Bird (very early producer)

Dusky (TMV)

Imperial (TMV)

Rosa Bianca

Asian type

Ichaban

Tycoon

White

Cloud Nine (TMV)

The standard eggplant produces egg-shaped, glossy, purple-black fruit 7 to 10 inches long when fully mature. Only a few plants are needed to meet the average family's needs. The long, slender Asian-type eggplants have a thinner skin and more delicate flavor. Both standard and miniature eggplants can be grown successfully in containers, but standard varieties yield a better crop. White ornamental varieties are available and edible, but they are of poor eating quality.

Problem Diagnosis for Eggplant

Problem	Probable cause	Comments
Deformed, curled leaves. Plants stunted. Small, soft-bodied insects on undersides of leaves. Sticky honeydew or black sooty mold may be present.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Small leaves with irregular mottle.	mosaic viruses	Plant TMV-resistant varieties.
Small holes in leaves; on lower leaves more than top ones.	flea beetle	Tiny black beetles that jump. Consult UC IPM Pest Notes or Flint 1998 for management options.
White, frothy foam on stems; insects visible beneath foam.	spittle bugs	Green insects. Tolerate. Do not cause significant damage.
Leaves wilt, turn yellow, then brown. Tiny white flies flutter when plant is disturbed.	whiteflies	Consult UC IPM Pest Notes or Flint 1998 for management options.
Dark-colored dieback from growing tip. Fruit may have orange, yellow rings.	spotted wilt virus	Spread by thrips. Control weeds that are host of virus and vector.
Plants do not grow. Blossoms drop off. Fruit does not develop.	climate too cool; wrong variety	Plant in warmer weather. Plant recommended varieties.
Plants wilt and die. Brown streaks inside root and lower stem visible when stem is split lengthwise.	Verticillium wilt	Caused by soilborne fungus. Avoid planting in soil previously planted to potato, tomato, or cucurbits.
Leaves roll downward. No stunting; no yellowing of new leaves.	physiological leaf roll	Not caused by pathogen; no action needed.
Buds or fruit turn yellow; buds or young fruit may drop from plant. Fruit have holes, become misshapen, develop blotches.	pepper weevil	Adults are dark beetles $^1/_8$ in long. Larvae are white, legless, found inside fruit. Destroy plants as soon as harvest is over to reduce problem next year. Destroy nightshade plants, an alternate host.
Normal-colored fruit, but small and flattened in shape. Few to no seed inside.	poor or incomplete pollination	Plant in full sunlight. Tap flowers at midday to aid pollination.
Large, sunken, water-soaked spot develops on blossom end of fruit; spot turns black and mold may develop.	blossom end rot	Can be caused by uneven moisture supply. Give uniform irrigation. Supply water during dry periods. Mulch.

Plant and handle eggplant in the same way as tomato; eggplant is slightly more sensitive to cold than tomato. Warm to hot weather throughout the season is necessary for good production. Seed germinate quickly at 70° to 90°F, and plants should be grown for 8 to 9 weeks before setting them out. Cold temperatures stop plant and root growth, reducing plant vigor and yields. Using hot caps or row covers protects plants from cold conditions.

Although eggplant does well in hot weather, it must have well-drained soil and does not thrive in very humid areas. Pick standard-type fruit when they are about 4 to 6 inches in diameter. Test for maturity by pressing with the thumb. If the flesh springs back, the fruit is green; if it does not and an indentation remains, the fruit is mature. Harvest when the fruit is about halfway between these stages. Mature fruit should not be left on the plant because they reduce overall productivity. Use a knife or pruning shears to cut the fruit from the plants.

Problem Diagnosis for Endive

See table 13.5 for general techniques to recognize and manage common problems associated with endive. A common disease of endive is downy mildew. Common insect pests that attack endive include flea beetles, aphids, armyworms, leafhoppers, snails, and slugs.

Problem Diagnosis for Fennel

There are few serious problems in growing this crop. If problems occur, see table 13.5 for general techniques to recognize and manage possible problems and consult the UC IPM Pest Notes or Flint 1998.

Endive *(Cichorium endivia)*

Recommended Varieties

Full Heart Batavian (smooth-leaved escarole)

Large Green Curled (deeply cut, curly leaves)

Plant and grow endive as you would lettuce, although it is hardier and may be produced as a winter crop in many locations where lettuce will not grow. Endive yields for a longer time than lettuce. The crop is ready for harvest 90 days after planting. When the plants reach 12 inches in diameter, tie the leaves together at the top to blanch the hearts. Do not tie the leaves when they are wet; this may cause decay.

Harvest when the hearts are well blanched. Colder temperatures and blanching result in a milder taste. The crop can be used unblanched by harvesting the outer leaves (as with chard), rather than harvesting the entire plant. Endive can be used in salads as greens or as a garnish.

Fennel, Florence Fennel, Finochio, Sweet Anise *(Foeniculum vulgare)*

Recommended Variety

Florence

Fennel, sometimes called finocchio or sweet anise, is a biennial or short-lived perennial vegetable and culinary herb crop that is usually grown as an annual. The variety Florence fennel is grown as a vegetable whose principal edible portions are the stem base and the enlarged bases of the leaf petioles, which overlap each other to form a compact bulb. However, all parts of the leaves are edible. Fennel can be eaten cooked or raw, like celery; because of its light licorice taste, it is used in flavoring. It also stores well. Seed is used as a flavoring. Fennel requires a long, cool growing season and is most commonly grown from seed. Soaking seed for a few days prior to planting increases germination. Florence fennel is harvested by using a knife to cut bulbs near the soil line when they become 2 inches or larger

in diameter. If grown to maturity, varieties other than Florence can grow to 3 feet or taller and may require staking or other support to remain upright. Plants grown to full maturity flower and produce seed that can be collected for culinary use, or they can be allowed to self-sow in the garden, which enables continuity of the planting. Plants grown to maturity can be cut to the soil line in the fall and will usually regrow the following growing season.

Garlic *(Allium sativum)*

Recommended Varieties

California Late

California Early

Garlic, if correctly handled, grows well in most parts of California. A few feet of row give an ample supply. Plant in fertile soil in late fall, winter, or early spring. Fall planting is best if winters are not severe. Give the crop the same care as described for onions. Harvest when the plant tops begin to die. Use a garden fork to lift bulbs out of the ground because pulling plants by hand could crack bulbs and reduce storage life. Let bulbs dry outdoors in the sun for about 3 weeks until the skins become papery. If you only grow a few plants, store the bulbs by braiding the tops and hanging the rope of garlic in a cool, dry place for use as needed.

Elephant garlic is a popular garden vegetable. It is similar to garlic, except that the bulb consists of one or two large cloves and numerous small cloves at the base. Cultural requirements and culinary aspects are similar to those of garlic.

Garlic is related to onions, leeks, and chives (members of the *Allium* genus) and suffers from similar pest, disease, and cultural problems.

Kale *(Brassica oleracea* var. *acephala)*

Recommended Varieties

Vates Dwarf Blue Curled (finely curled dwarf leaves)

Salad Savoy (curled, colorful leaves, green on white)

Winterbor (finely curled, blue-green)

Ornamental (heavily fringed leaves, red on green or white on green; for containers or bedding plants)

Kale is a cool-season vegetable that can be used raw as salad greens, as a garnish, as an ornamental in the flower bed, or cooked. Plants produce rosettes of very decorative cut or curled leaves with colors rather than forming tight heads. Collards are a type of kale with larger, smoother leaves resembling cabbage. Kale greens have a healthy supply of vitamins and minerals and few calories. Slight frosts sweeten kale's flavor, whereas high temperatures and hot sun can lead to bitter leaves. Harvest leaves a few at a time, starting with the outer leaves first.

Kohlrabi *(Brassica oleracea* var. *gongylodes)*

Recommended Varieties (Disease resistance, table 13.6)

Grand Duke (AAS)

Early White Vienna

Purple Vienna

In appearance, kohlrabi resembles an aboveground turnip with the leaves attached to the edible, enlarged, swollen, fleshy stem, which enlarges to about 4 inches in diameter. Harvest at about 2 inches in diameter, when it is less vigorous and less stringy. Peel and eat kohlrabi raw in salads or cook by steaming. The flavor is similar to turnips, and the texture resembles that of water chestnuts.

Leek *(Allium ampeloprasum* or *A. porrum)*

Recommended Varieties

Large American Flag

Electra

Titan

The leek belongs to the *Allium* genus, like onions, but it has only a mild onion flavor. The plant does not form a bulb and grows to about 1 to 1½ inches in diameter. Leeks are usually grown as a fall crop

Problem Diagnosis for Garlic

See "Problem Diagnosis for Onion."

Problem Diagnosis for Kale

As a member of the Brassica family, kale is related to cabbage, cauliflower, turnips, kohlrabi, mustard greens, broccoli, and brussels sprouts. Kale suffers from similar pest insects, diseases, and cultural problems that plague its relatives. See "Problem Diagnosis for Cabbage."

Problem Diagnosis for Kohlrabi

As a member of the Brassica family, kohlrabi is related to cabbage, cauliflower, turnips, kale, mustard greens, broccoli, and brussels sprouts. Kohlrabi suffers from similar pest insects, diseases, and cultural problems that plague its relatives. See "Problem Diagnosis for Cabbage."

Problem Diagnosis for Leek

As a cousin of onions and garlic, leeks suffer from similar pest insects, diseases, and cultural problems. See "Problem Diagnosis for Onion."

in most areas and may be left in the field for some time after maturity. When the plants are almost full size, hill the soil around them to a height of 6 to 8 inches to blanch the lower parts of the plants.

Lettuce *(Lactuca sativa)*

Recommended Varieties (Disease resistance, table 13.6)

Butterhead (Boston, Bibb)

- Buttercrunch (AAS, B)

Batavian (French Crisp, Summer Crisp)

- French
- Laura (B)
- Loma
- Nevada (DM)
- Sierra (red) (H, B)

Romaine (cos)

- Parris Island (B, LMV, TB)
- Valmaine (DM)

Crisphead (iceberg) (difficult to grow in home gardens)

- Great Lakes (AAS, TB)
- Vanguard (LMV)
- Calmar (TB)
- Empire (B, TB)

Loose leaf

- Salad Bowl (AAS, B)
- Oak Leaf (B, H)
- Red Sails (deep red-bronze) (AAS, B)
- Ruby (red shading) (H)
- Royal Green

Lettuce, a cool-season vegetable, is extremely sensitive to high temperatures. If direct-seeded during high temperatures, seed dormancy may result. It is usually more successful to use transplants that are 3 to 4 weeks old. Time your planting of the crop so it matures during periods of cool temperatures. Several types of lettuce, described below, are commonly grown in home gardens.

Crisphead, also known as iceberg, is the lettuce most widely available as a fresh-market type. It has a tightly compacted head with crisp, light green leaves. Many home gardeners find this type difficult to grow because it requires a long cool season; some of the most advertised varieties are not heat resistant and tend to go to seed (bolt) as soon as temperatures go up. High temperatures during maturity may result in premature seed stalk development and internal tip burn, especially in crisphead types. For best results, select a slow-bolting variety and start seed indoors in late winter or late summer. Transplant in early spring or fall to take advantage of cool weather; mulch well to keep soil temperatures from fluctuating and to hold moisture in. Thin or space crisphead types so the plants are 10 to 12 inches apart. An organic mulch is more suitable than black plastic after soil warms up. Mulching also keeps soil off the leaves, reducing the chances of disease from soilborne organisms.

Butterhead, or bibb, lettuce, is a loose-heading type with dark green leaves that are somewhat thicker than those of iceberg lettuce. Butterheads develop a light yellow, buttery appearance and are very attractive in salads. They may be started indoors for an even longer season. Bibb lettuce develops bitterness readily if temperatures get too high.

Romaine, also known as cos, is a fairly nutritious lettuce that deserves attention. It too is relatively easy to grow from transplants, forming upright heads with rather wavy, attractive leaves. Thin or space romaine types to 6 to 8 inches apart.

Most gardeners who grow lettuce raise the loose-leaf type, either with green or reddish leaves. This type is a fast-growing, long-lasting lettuce used for salads, sandwiches, and in wilted lettuce salads. Loose-leaf lettuce may be grown in wide beds that facilitate frequent cutting and make maximum use of garden space. Thin or space leaf types to 4 to 6 inches apart.

Cultivate carefully because it is shallow rooted. Use frequent, light waterings and sidedress two or three times with nitrogen

Problem Diagnosis for Lettuce

Problem	Probable cause	Comments
Seedling plants damaged by caterpillars feeding in crown. Plants may die.	corn earworm; armyworms	Consult UC IPM Pest Notes or Flint 1998 for management options.
Curled, distorted leaves. Stunted plants. Green, pink, or black aphids on undersides of leaves, stems, or roots.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves have ragged holes. Holes bored into heads of lettuce. Leaves devoured.	loopers	Use *Bacillus thuringiensis*. Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves skeletonized or almost totally destroyed. Small holes in leaves or leaves heavily skeletonized.	armyworms; vegetable weevil	Attacks radish, carrot, turnip also. Damage is spotty. Adults do not fly. Consult UC IPM Pest Notes or Flint 1998 for management options.
Inner leaves of head lettuce are black on edges.	hot weather	Do not plant head lettuce for harvest in warmest months. Plant heat-tolerant varieties.
Upper leaf surface has yellow to light green areas delineated by leaf veins. Undersurface has soft, downy white growth.	downy mildew	Most prevalent under cool, moist conditions. Remove damaged outer leaves at harvest. Remove sources of disease (old lettuce plants and wild lettuce) before planting. Use resistant varieties.
Lower leaves and whole plant wilt, get slimy. Hard, black sclerotia and white, cottony, moldy growth under lower leaves and plant crown.	Sclerotinia drop (lettuce drop)	Caused by a fungus.
Leaf veins lose green color and appear enlarged. Leaves appear puckered, ruffled.	big vein	Viroid disease associated with fine-textured, poorly drained soil. Do not overwater. Plant tolerant varieties. Plant so that air temperature is > 60°F to lessen severity of symptoms. Remove sick plants.
Edges of internal leaves are brown and rotten. Not visible from outside of head.	tip burn	Physiological disorder caused by calcium deficiency, aggravated by high soil fertility and high temperatures. Avoid excess potash. Keep nitrogen levels as low as possible. Avoid water stress. Keep calcium adequate. Use tolerant variety.
Leaves wilt temporarily, may turn dark green or gray-green. Smaller roots dead. Taproot in cross section is yellow, red, or brown.	ammonia injury	Common with urea fertilizer and chicken manure. Keep ammonium forms of nitrogen out of seed row. Cool, waterlogged soil is a problem.
Silvery leaves. Upper leaf surface separated from rest of leaf by water droplets.	frost injury	Sudden temperature drop below freezing will injure lettuce.
Leaves faintly mottled. Yellowed, stunted plants.	viruses	Plant resistant varieties and use virus-free seed, if available. After symptoms occur, there is no practical control. Aluminum foil mulches may help prevent infection by aphid and leafhopper-transmitted viruses. Plants showing symptoms near harvest are edible. Plants that show symptoms early may produce no or small heads. Remove infected plants. Control weeds and insects.
Silvered areas on underside of leaves of head lettuce. Yellowed lower leaves have tiny brown spots.	smog	Do not grow head lettuce in smoggy months.
Plants begin to grow tall and send up flower stalks.	high temperatures	Prolonged hot weather causes seed stalks to form. Grow lettuce only during cool months. Plant varieties resistant to bolting and heat. Leafy types are more tolerant of heat. Plant in partial shade among corn in midsummer, or plant early or late to mature during cool weather.
Bitter taste.	high temperatures	See above.
Torn areas on leaves.	birds	Consult UC IPM Pest Notes or Flint 1998.
Stem, lower leaves rotten. Dense, fuzzy gray mold on affected areas.	Botrytis gray mold	Caused by a *Botrytis* fungus. Rotate crops; remove old plant debris. Plant in well-drained area.
Sunken, water-soaked spots appear on lower leaves, which turn brown and slimy.	Rhizoctonia bottom rot	Caused by a soilborne fungus. Rotate crops; remove old plant debris. Plant in well-drained area.

Problem Diagnosis for Mustard

As a member of the Brassica family, mustard is related to cabbage, cauliflower, turnips, kale, kohlrabi, broccoli, and brussels sprouts. Mustard suffers from similar pest insects, diseases, and cultural problems that plague its relatives. See "Problem Diagnosis for Cabbage."

Problem Diagnosis for Okra

See table 13.5 for general techniques to recognize and manage the common problems associated with okra. Nematodes, aphids, corn earworm, and mites cause problems in okra.

to encourage rapid growth; overwatering can encourage root and leaf diseases. Mulches are helpful in maintaining soil moisture and keeping lettuce leaves off the ground.

Lettuce planted in very early spring should be given full sun so that the soil will warm enough for rapid growth. For long-season lettuces, plant so that crops such as sweet corn, staked tomatoes, pole beans, or deciduous trees will shade the lettuce during the hottest part of the day. Interplanting—planting between rows or within the row of later-maturing crops like tomatoes, broccoli, and brussels sprouts—is a space-saving practice. Most lettuces are attractive in flower borders and in containers.

Lettuce is best planted in succession or by using different varieties that mature at different times. Thirty heads of romaine lettuce harvested at once can present a major storage problem! Leaf and bibb lettuces do well in hotbeds or greenhouses during the winter and in cold frames in spring and late fall.

Harvest heading types when they are firm but not hard. Hardening decreases flavor and other quality characteristics. Bibb lettuce is mature when the leaves begin to cup inward to form a loose head that will never become compact. Romaine is ready to use when the leaves have elongated and overlapped to form a fairly tight head about 4 inches wide at the base and 8 to 10 inches tall. Crisphead is mature when leaves overlap to form a head similar to that available in groceries; heads will be compact and firm.

Harvest loose-leaf (nonheading) types when they reach full size, which is usually about 3 to 6 inches tall. Cut off and use the older, outer leaves first by removing them at the base of the plant. As the inner leaves reach 3 to 6 inches in height, they may be harvested by trimming the entire plant to within 1 to 2 inches of the soil using a sharp knife or pair of shears. Many loose-leaf varieties will regrow and can be harvested repeatedly if growing conditions remain favorable. Correctly harvested and trimmed lettuce stores well in the refrigerator, where it should keep about 2 weeks. If lettuce is to be stored, harvest when dry but early in the day when water content of plants is high. Remove outer leaves but do not wash. Place in a plastic bag and store in the crisper drawer of the refrigerator.

Mustard Greens *(Brassica juncea)*

Recommended Varieties

Tendergreen

Southern Giant Curled (curly, deeply cut leaves)

Florida Broadleaf (large, smooth leaves)

Cultivated mustard varieties are more productive than wild mustard for use as spring greens. Grow and handle the crop as directed for spinach. Harvest by cutting or snapping off the outer leaves, allowing new inner leaves to increase in size. Do not allow the leaves to reach an excessive size, as the petioles become stringy. Small leaves are tender enough to use raw in salads; larger leaves are better when cooked.

Okra *(Abelmoschus esculentus)*

Recommended Varieties (Disease resistance, table 13.6)

Clemson Spineless (AAS)

Blondy (compact plants with whitish pods) (AAS)

Okra, sometimes called gumbo, is a summer and fall crop. Do not plant seed until the soil is warm. Soak seed in water for 24 hours before planting. Plant only those seed that are swollen. Plants grow to a height of 4 to 5 feet and produce pods in about 60 days. Plants must be staked. After the pods begin to form, pick them every 2 or 3 days. The plants stop bearing if you allow the pods to ripen on the stems.

Onion *(Allium cepa)*

Recommended Varieties

Green bunching (scallions; best quality obtained by growing seed or transplants)

Evergreen White

Southport White

White Sweet Spanish

White Lisbon

Tokyo Long White

Short day

Bermuda

Grano (red or white)

Granex (red or white, also called Vidalia onions)

California Early Red

Intermediate day

Italian Red

Stockton (red, white, or yellow)

Long day

Fiesta (yellow sweet Spanish type)

Yellow Sweet Spanish

White Sweet Spanish

Southport Globe (red or white)

Onions are biennial plants that are normally grown as annuals. Depending on the area of California you live in, you can grow onions from seed, sets, or transplants. Seed requires a longer growing period than other methods, and the plants have to be thinned. However, it is the cheapest method and is the one most commonly used. Sets are small, immature onion bulbs that are planted the same way as seed. They are an easy method for growing onions, but the varieties used to produce sets are frequently not well adapted to California or frequently bolt (go to seed) rather than bulbing up. If sets are used, be certain to verify the variety is adapted to your area and meets the day length requirement your region offers. Sets can produce a quick crop of green onions, though the quality is much lower than green onions produced by seed or transplants. Transplants are an easy method for producing an early crop, but you may have to raise your own plants because well-adapted varieties are not always available from nurseries.

Onions are often grouped according to taste. The two main types are strong flavored (American) and mild or sweet (sometimes called European). Each has three distinct colors: yellow, white, and red. Generally, the American onion produces bulbs of smaller size, denser texture, stronger flavor, and better keeping quality than European types. Globe varieties tend to keep longer in storage.

Onions vary in their pungency, or hotness. In general, the softer varieties, such as Granex, Grano, and Sweet Spanish, are milder than the harder varieties, such as Southport White Globe. The mild onions are preferred for fresh consumption, but the stronger ones are better for cooking. Though not grown in California, the widely known Vidalia and Maui onions are Granex-type, short-day varieties, while Walla Walla onions are a Sweet Spanish, long-day type. Sweet onions, regardless of the actual varieties, are sometimes marketed as sweet Bermuda or Spanish onions.

Onion varieties have different requirements regarding the number of daylight hours (photoperiod) required to initiate bulb development and form a bulb. An onion plant will bulb up only after experiencing its critical day length for several weeks; the bigger the plant receiving the light stimulus, the bigger the bulb. Plants with 12 to 15 leaves are considered the ideal size to begin bulbing. If an onion variety is described as long day, it sets bulbs when it receives 14 or more hours of daylight. Short-day varieties set bulbs with about 12 hours of daylight, and intermediate-day onions set bulbs with about 13 to 14 hours of daylight.

Onions are affected by temperature in addition to day length. Average daytime temperatures less than about 70°F retard bulb formation. Seedlings or young transplants exposed to several days of temperatures well below this critical temperature, followed by a period of weather

Problem Diagnosis for Onion

Problem	Probable cause	Comments
Seedlings are pale, thickened, deformed. Older plants are stunted, limp. Leaf tips dying back. Bulbs swollen at base.	stem and bulb nematode	Use certified seed. Do not plant garlic or onions in areas where onions, garlic, leeks, or chives grew in previous years. Parsley and celery are also hosts. Remove and destroy infested culls.
Leaves turn silvery; may also have white streaks, blotches.	onion thrips	Most common during dry, warm weather. Consult UC IPM Pest Notes or Flint 1998 for management options.
Tiny bulbs. Roots look white and normal.	wrong variety; planted at wrong time; weed competition	Plant right variety at proper time. Garlic and onions do not compete well with weeds; control weeds.
Seed stalks develop.	cold weather after plants are 6–10 weeks old	Plant right variety at proper time. Do not overwinter.
Roots rotten and pink. Yields drastically reduced.	pink root	Caused by a soilborne fungus. Grow a pink root-resistant variety. Rotate crops to reduce disease severity.
Tunnels and cavities in bulb and underground stem. Plant may die or become wilted and yellow. Tips may turn brown.	onion maggot	Adults are small flies; larvae are off-white, legless. Preventive controls only. Nothing practical can be done once pest occurs on growing crop. Destroy culled garlic and onions after harvest. Consult UC IPM Pest Notes or Flint 1998 for management options.
Yellow or white areas on leaves. Leaves and stalks bend, wilt, and die. Soft, white to purple spore (mold) growth during wet, humid weather.	downy mildew	Fungus attacks plants only in the Allium (onion) family. Destroy old plant debris. Keep soil well drained. Allow plants to dry out between irrigations. Keep air circulating. Plant resistant varieties.
Plants collapse. Bulbs have soft, watery rot. Leaves or bulbs have white, fuzzy growth speckled with black bodies.	white rot	Caused by fungi. Destroy diseased plants. To prevent spread in soil, do not compost. Rotate crops. Fungus survives in soil for years.

at or above this temperature while day length is increasing, may produce flower stalks before they mature or form bulbs (bolt). Timing the planting of seed, transplants, and sets is critical to avoid this combination of factors (see table 13.2 for recommended planting dates).

The variety, planting date, and region of the state are extremely important in the production of a good onion bulb crop. Before buying and planting, obtain advice from an experienced local gardener or your local UC Cooperative Extension farm advisor or master gardener office. In general, if you live south of Bakersfield, use short-day varieties seeded or transplanted in October for June harvest. In nondesert locations you can also plant seed and transplants of intermediate-day varieties in February for harvest in late summer or fall. Sets and long-day varieties are not recommended in this southern region for bulb production. If you live in Bakersfield or farther north, seed or transplant intermediate- or long-day varieties from January through March for late summer or fall harvest. In some northern areas it is also feasible to seed or transplant short-day varieties from November through January for late-spring or summer harvest.

Dry onions are ready to harvest when the tops fall over (approximately 6 months

after planting). Pull onions and let them dry for a few days on top of the ground. Cover the bulbs with the tops to prevent sunburn. When the tops and necks are dry, remove the tops and store the bulbs in a cool, dry place. Or, you can leave the tops on, braid them, and hang them in a cool, dry place. If onions are allowed to form seed stalks, the center of the bulb becomes woody, undesirable to eat, and unsuitable for long storage.

Green onions are of highest quality when grown in relatively cool temperatures (see table 13.2). Plant green onions four to six times thicker than you would dry bulb onions. Harvest green onions when they are ¼ to ½ inch in diameter.

Problem Diagnosis for Parsley

There are few serious problems in growing parsley aside from heat stress in hot summer periods of inland valleys and deserts. Spider mites occasionally damage plants, causing yellow or whitish deformed leaves. See table 13.5 for general techniques to recognize and manage other possible problems associated with parsley and consult the UC IPM Pest Notes or Flint 1998.

Parsley *(Petroselinum crispum)*

Recommended Varieties

- Extra Curled Dwarf
- Hamburg (forms edible white roots)
- Moss Curled
- Paramount (dark green, very curled)
- Plain or Single (smooth-leaf type)
- Italian Flat

Parsley seed germinates and emerges quite slowly. It is best to purchase transplants or start the seed indoors to produce transplants for the spring. The plants will overwinter in mild climates, but they develop seed stalks as the days lengthen and the temperatures increase in the late spring. Harvest in the cool, early-morning hours to maintain maximum flavor and parsley odor. Pinch or cut off the mature outer stems to allow the inner leaves and stems to develop for later harvest. Coriander *(Coriandrum sativum)*, also known as cilantro, resembles and is related to Italian Flat parsley but has a stronger flavor and odor.

Problem Diagnosis for Parsnip

See table 13.5 for general techniques to recognize and manage common problems associated with parsnip. Nematodes, armyworms, cabbage root maggots, flea beetles, and leafhoppers cause problems in parsnip.

Parsnip *(Pastinaca sativa)*

Recommended Varieties

- All America
- Hollow Crown
- Harris Model

Grow parsnips by the same methods as described for carrots. Parsnips require a deep, well-worked seedbed for optimal root development and sizing. Roots can exceed 12 inches long. The seed germinates quite slowly, although presoaking it in water for a day before planting assists germination. The crop has a long growth period of 4 months or more. Eating quality is improved by frost. You can store parsnips in the ground if frosts are not severe; otherwise, store them in moist, cool conditions. Roots become tough if left in the soil too long or if seed stalks begin to develop.

Pea *(Pisum sativum*, green garden type; *Pisum sativum* var. *saccharatum*, China, snow, or sugar type; *Pisum sativum* var. *macrocarpum*, snap type)

Recommended Varieties (Disease resistance, table 13.6)

China, snow, or sugar

- Dwarf Gray Sugar (F)
- Mammoth Melting Sugar (F)

Cowpeas (southern peas, black-eyed peas)

- California Blackeye

Green garden (dwarf vines)

- Little Marvel
- Progress No. 9 or Laxton's Progress (F)
- Greater Progress (F)

Green garden (large vines requiring support)

- Freezonian (AAS, F)
- Green Arrow (DM, F, VR)
- Maestro (M, F, VR)

Snap (thick, edible pods)

- Sugar Ann (dwarf) (AAS, PM)
- Sweet Snap (semidwarf) (PM)
- Sugar Rae (dwarf) (PM)
- Sugar Daddy (stringless, dwarf) (PM)
- Sugar Snap (AAS)
- Super Sugar Mel

Bush peas have a shorter, earlier production period than the pole types, which require extra work but yield more and

Problem Diagnosis for Pea

Problem	Probable cause	Comments
Leaves, stems covered with sticky honeydew, black sooty mold.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Holes in leaves; black-spotted, greenish yellow beetles present.	cucumber beetles	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves skeletonized. Groups of tiny caterpillars feeding together.	armyworms	Consult UC IPM Pest Notes or Flint 1998 for management options.
Very fine, whitish to yellowish stippling on upper leaf surface; fine webbing on undersurface.	spider mites	Consult UC IPM Pest Notes or Flint 1998 for management options.
Deformed pods; surface scarring of pods.	thrips	Control weeds.
Winding white trails mined in leaves, stems, or pods.	leafminers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Semicircular notches on leaf margins. Young plants may be chewed at ground level.	pea leaf weevil adults	When plants have grown past the 6-leaf stage, treatment is not necessary.
Leaves with white-purple cottony growth on underside only. Tops of leaves have yellow blotches. Dark spots on pods. Plants water soaked.	downy mildew	Caused by a soilborne or seedborne fungus. Plant resistant variety.
White powdery growth on top side of leaves. Leaves curled, dried out.	powdery mildew	Caused by a fungus. Favored by warm, dry days and cool, damp nights. Plant resistant varieties. Remove plant debris to destroy overwintering fungus.
New growth distorted, curled, mottled. Pods distorted. Plants may die.	viral disease	Usually spread by aphids. Plant resistant varieties. Remove and destroy infested plants as soon as possible. Control weeds. Control insects.
Yellowing of lower leaves. Stunted growth. Cross section of lower part of stem may show reddish orange discoloration.	Fusarium wilt	Caused by soilborne fungus. Pull up and destroy infected plants. Do not replant peas in same soil for 5–10 years. Plant resistant varieties and rotate crops.
Plants stunted; vines off-color.	root rot complex	Raised beds improve drainage.
Roots rotten or absent. Occurs in patches along rows.	poor soil drainage associated with low or wet spots	Rotate crops. Avoid wet soil or low areas where water collects.
Small, chlorotic spots in spring.	stink bugs	Trap adults under boards. Turn over in morning and handpick pest insects.
Pods partially or entirely removed.	birds	Consult UC IPM Pest Notes or Flint 1998.
Plants stop producing peas, leaves turn yellow, then brown, and die.	hot weather	Peas are cool-season vegetables. Plant early; plant heat-resistant varieties.

produce for a longer time. Peas do best when grown during cool weather; warm weather shortens the harvest season. Bush types grow in most areas of California; vine types do best along the coast. It is essential to provide support for the climbing vine types. Do not use overhead irrigation, because it increases the incidence of mildew.

Harvest peas when the seed and pods are well developed but tender enough so they may be crushed between the fingers without separating into halves. Harvest edible-pod types at the first sign of seed development. The sugar content of peas readily converts into starch; peas become overmature quickly, and starch conversion continues after picking. Therefore, refrig-

Problem Diagnosis for Pepper

Problem	Probable cause	Comments
Deformed, curled leaves. Plants are stunted. Small, soft-bodied insects on undersides of leaves. Sticky honeydew or black sooty mold may be present.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Buds or fruit turn yellow. Buds or young pods may drop from plant. Pods have holes, become misshapen, develop blotches.	pepper weevil	Adults are dark beetles $^1/_8$ in long; larvae are white, legless, found inside fruit. Destroy plants as soon as harvest is over to reduce problem next year. Destroy nightshade plants, an alternate host.
Small leaves with irregular mottle.	mosaic viruses	Plant varieties resistant to tobacco mosaic virus (TMV).
Dark-colored dieback from growing tip. Pods may have orange, yellow rings.	spotted wilt virus	Spread by thrips. Control weeds that are host of virus and vector.
Plants do not grow. Blossoms drop off. Fruit do not develop.	climate too cool; wrong variety	Plant in warmer weather. Plant recommended varieties.
Plants wilt and die. Brown streaks inside root and lower stem visible when stem is split lengthwise.	Verticillium wilt	Caused by soilborne *Verticillium* fungus. Avoid planting in soil previously planted to potato, tomato, or cucurbits.
Leaves roll downward. No stunting; no yellowing of new leaves.	physiological leaf roll	Not caused by pathogen; no action needed.
Small holes in leaves; on lower leaves more than top ones.	flea beetle	Tiny black beetles that jump. Consult UC IPM Pest Notes or Flint 1998 for management options.
White, frothy foam on stems; insects visible beneath foam.	spittle bugs	Green insects. Tolerate. Not a cause of significant damage.
Leaves wilt, turn yellow, then brown. Tiny white flies flutter when plant is disturbed.	whiteflies	Consult UC IPM Pest Notes or Flint 1998 for management options.
Normal-colored fruit, but small, flattened in shape. Few to no seed inside.	poor or incomplete pollination	Plant in full sunlight. Tap flowers in midday to aid pollination.
Fruit have visible worms or holes where worms entered.	corn earworm; omnivorous leafroller	Consult UC IPM Pest Notes or Flint 1998 for management options.
Large, sunken, water-soaked spot develops on blossom end of fruit; spot turns black and mold may develop.	blossom end rot	Can be caused by uneven moisture supply. Give uniform irrigation. Supply water during dry periods. Mulch.

erate or freeze edible-pod peas immediately after harvest and cook or process (can or freeze) standard peas soon after shelling.

Pepper *(Capsicum annuum)*

Recommended Varieties (Disease resistance, table 13.6)

Hot

- Tam Mild Jalapeño (mild heat with Jalapeño flavor) (PVY)
- Jalapeño Delicias
- Anaheim TMR 23 (chili pepper, moderately hot) (TMV)
- Anaheim (standard hot chili)
- Cayenne Long Red Slim (hot)
- Hungarian Yellow Wax (popular for canning, moderately hot)
- Serrano Chili Pepper (tabasco type)

Sweet bell

- Bell Boy (AAS, TMV)
- California Wonder (TMV)
- Yolo Wonder (TMV)

Problem Diagnosis for Sweet Potato

See table 13.5 for general techniques for recognizing and managing the common problems associated with sweet potato. Nematodes, aphids, flea beetles, leafhoppers, and wireworms cause problems in sweet potato plantings. See white potato, below, and consult the UC IPM Pest Notes or Flint 1998.

Keystone Resistant Giant (TMV)

Jupiter (TMV)

Golden Summer Hybrid (yellow when fully mature) (TMV)

Golden Bell (yellow when fully mature)

Early Pimento (used fresh or for canning) (AAS)

Sweet yellow or cubanelle

Sweet Banana (AAS)

Gypsy (AAS, TMV)

Hy-Fry

Cubanene

Nardello

Corni de Toro

There are two types of peppers: the large-fruited, mild-flavored bell types, preferred by many gardeners, and the hot varieties, which may be used green. The mild peppers include bell, banana, pimiento, and sweet cherry, while the hot peppers include cayenne, celestial, large cherry, serrano, tabasco, and jalapeño. Hot peppers are usually allowed to ripen fully and change colors (except for jalapeños) and have smaller, longer, thinner, and more tapering fruit than sweet peppers. Yields are smaller for hot peppers.

Bell peppers, measuring 3 or more inches wide by 4 or more inches long, usually have three to four lobes and a blocky appearance. They are commonly harvested when green, yet turn red or yellow when fully ripe. About 200 varieties are available, including specialty colored varieties that are deep red, purple, and other colors.

Banana peppers are long and tapering and harvested when yellow, orange, or red. Another sweet pepper, pimiento, has conical, thick-walled fruit, 2 to 3 inches wide by 4 inches long. Most pimientos are used when red and fully ripe. Cherry peppers vary in size and flavor. They are harvested orange to deep red.

Slim, pointed, slightly twisted fruits characterize the hot cayenne pepper group. They can be harvested either green or red and include varieties such as anaheim, cayenne, serrano, and jalapeño. Celestial peppers are cone shaped, ¾ to 2 inches long, and very hot. They vary from yellow to red to purple, making them an attractive plant to grow. Slender, pointed tabasco peppers, 1 to 3 inches, taste extremely hot and include such varieties as Chili Piquin and Small Red Chili.

The cultural and climatic requirements for both types of peppers are the same as those recommended for tomatoes. You can start peppers in a hotbed or cold frame for transplanting, or you can buy small plants from the nursery and set them out in the garden. Peppers generally need a long, warm growing season but grow slowly during cool periods. When temperatures approach 100°F, pollination, fruit set, and yield are reduced. After the soil has thoroughly warmed in the spring, you can set out 6- to 8-week-old transplants to get a head start toward harvest. Practice good cultivation and provide adequate moisture. Mulching can help conserve water and reduce weeds.

Harvest fruit of mild peppers when they are green or red-ripe. When allowed to mature on the plant, most varieties turn red, become sweeter, and increase in vitamin A and C content. Cut, instead of pulling, to avoid breaking branches. Hot peppers that you plan to dry should be allowed to ripen on the plant. Hot peppers turn red when ripe; they may then be cut with 1 inch of stem attached, strung on a thread, and hung in a sunny place until dry and brittle. Use a sharp knife for cutting, as the stems are tough.

Potato, Sweet *(Ipomoea batatus)*

Recommended Varieties

Dry fleshed (yellow)

Jersey

Moist fleshed (yams)

Garnet (dark red)

Jewel (deep orange)

Sweet potatoes are modified roots and are known as yams to some gardeners, but the true yam is a different plant (*Dioscorea*

spp.) grown in tropical climates for its huge tubers. Moist-fleshed varieties are the sweet potatoes commonly referred to as yams.

Sweet potatoes grow best in light, sandy soil and are sensitive to temperatures below 50°F. For this reason, sweet potatoes do not grow well along the north coast or in the northern sections of the state.

Grow sweet potatoes from sprouts, or slips, produced by the following method: Place small sweet potatoes in a hotbed about March 1 (about February 1 for desert areas); cover with 3 to 4 inches of sand; keep the bed moist. Maintain a soil temperature of 70° to 75°F in the hotbed. In about 6 weeks, sprouts about 8 inches long are ready for transplanting. Pull the sprouts and transplant them to raised beds. You may grow several crops of sprouts from the same planting. After setting out the sprouts, apply several light irrigations throughout the growing season.

You can harvest sweet potatoes when slightly immature if they are of suitable size; otherwise, leave them in the ground until the roots are full grown and the vines begin to turn yellow. However, if the leaves are killed by frost before they yellow, cut them off, dig up the roots, and store them at once in boxes in a warm, moist place. Do not bruise the roots when digging, as this increases the possibility of decay. Sweet potatoes improve during storage because a part of the starch content is converted into sugar.

Potato, White (Irish) *(Solanum tuberosum)*

Recommended Varieties (Disease resistance, table 13.6)

White Rose (LB)

Kennebec (LB, VR)

Chieftain

Norgold Russet

Red Lasoda

Yukon Gold

Many specialty varieties also available

Grow white potatoes from sections of tubers. Do not use grocery store potatoes or potatoes from your own garden as a source of seed. Buy seed potatoes from a nursery that displays a Certified Seed Potato tag. If the seed potatoes are not already cut, cut the tubers into pieces weighing 1½ to 2 ounces. Make sure each piece has at least one eye. Store the freshly cut pieces at room temperature for 1 to 3 days before planting. This allows the cut surfaces to dry and form a callus, which decreases rotting.

To plant, drop the seed pieces into furrows 3 inches deep with the pieces spaced 6 to 12 inches apart. Closer spacing gives more but smaller potatoes at harvest. Fill in the furrow to ground level. When the potato plants emerge, cover with 3 inches of soil, making furrows between the rows that are at least 6 inches deep. You can also plant the seed pieces in premade beds. Apply nitrogen fertilizer at planting time.

Potatoes are shallow rooted and need light, frequent irrigations at least once a week during much of the growing season. Excessive irrigation, however, causes rotting. If soil moisture conditions are alternately wet and dry, potatoes become rough and knobby. Potatoes do not grow well in soil containing moderate or large amounts of clay; sandy or loamy soils are best.

When the plants are about 4 to 6 inches tall they should be “dirted,” using a hoe or a similar tool to pull about 3 to 4 inches of soil up to the plants. The seed piece should ideally be about 6 inches beneath the surface of the soil after the dirting process. When the tops have grown too large to allow cultivation, a finishing cultivation, sometimes called laying by or hilling up, is given. Laying by consists of throwing soil over the potatoes to prevent their exposure to sun, which can cause greening or scalding. A poisonous alkaloid makes green potatoes taste bitter and they should not be consumed.

Harvest early potatoes when large enough for table use. If you wish to store potatoes for later use, leave them in the

Problem Diagnosis for White Potato

Problem	Probable cause	Comments
Plants fail to emerge from ground after planting seed pieces.	soil organisms; market potatoes used as seed	Soil organisms can rot seed pieces. Potatoes bought at the market are often treated to prevent sprouting. Plant only certified seed potatoes. Cut them when sprouts begin to form, and plant seed pieces immediately. Plant when soil temperature is > 45°F.
Tunneling in tubers, also visible in stalks, leaves. Pink tuber eyes from excrement. Shoots wilting and dying.	potato tuberworm	Consult UC IPM Pest Notes or Flint 1998 for management options.
Curled, distorted leaves. Stunted plants.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves curled upward; older leaves turn yellow, then brown; margins of young leaves may be purple. Nodes and petioles are enlarged, twisted. Foliage rosetted. Aerial tubers may be visible. Tubers small, produced in chains. Entire plant brown, stiff, upright.	potato psyllid	Adults are size of aphids, winged, light gray to dark brown. Found on undersides of leaves. Immature forms are flat, disklike, yellowish with marginal fringe. Serious damage to young plants. Once tubers are formed, psyllids can be tolerated.
White stippling on upper leaf surface; leaf margins, tips yellow or brown. Plants stunted.	leafhoppers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves full of small holes. Tubers with bumps and shallow winding trails on surface.	flea beetles	Brown, black, or striped jumping beetles $^{1}/_{16}$ in long. Control usually not necessary. Peel away damage on tubers.
Bumps or pimples on tubers; brown spots in outer part of tuber flesh. Swellings on roots.	nematodes	Consult UC IPM Pest Notes or Flint 1998 for management options.
Poor crop in spite of good growing practices. Leaves rough, crinkled.	viruses	Plant certified seed potatoes.
Leaves turn grayish brown with rings of gray-white downy spores when humidity is high. Leaves and stems die. Tubers have brown purple scars on surface and rot in storage.	late blight	Caused by a fungus that infects potatoes, tomatoes, and other potato family plants. Problem mainly in coastal areas and Bakersfield. Destroy, remove volunteer potatoes before planting. Use resistant varieties, such as Kennebac or White Rose; do not plant highly susceptible varieties such as Yukon Gold. Plant certified tubers. Keep tubers covered with soil hills. Bordeaux mixture is protectant. Cut vines 1 in below soil surface and remove 10–14 days before harvest. Do not harvest under wet conditions. Eliminate all tubers and plants after harvest.
Plant leaves rolled, often with loss of dark green color and slowed growth. Brown speckling in stem end of tubers.	leafroll and other aphid-transmitted viruses	Use certified seed. Avoid saving seed potatoes from gardens. Use resistant varieties. Control insects. Control weeds.
Tubers knobby shaped or with cavities.	alternate wet and dry conditions	Keep soil moisture uniform. Do not plant in heavy soils.
Vines progressively decline and die earlier than normal. Brown streaks inside lower stem visible when stem split lengthwise.	Verticillium wilt	Caused by a soilborne fungus. Rotate crops. Avoid ground planted to tomatoes, peppers, eggplant, or cucurbits.
Tubers have brown streaks and what appears to be a root inside.	nutsedge rhizomes	Keep potato plantings free of nutsedge.
Scabby spots or pits on surface of tubers.	scab	Caused by a soilborne bacterium. Disease is cosmetic. Affected tubers are edible. Plant resistant varieties. If scab occurs, change varieties next year. Disease is favored by neutral to basic soil. Sulfur may be worked into soil to make it slightly acid and reduce disease.
Green tubers.	exposure to sun	Do not eat green part of potato tuber because of toxin. Mound soil up around planting.
Tubers have slimy, smelly rot.	soft rot	Bacterial disease. Plant in well-drained soil. Store properly.
Tubers show irregular white or brown cavities when cut open.	hollow heart	Caused when plants grow too rapidly. Do not overfertilize or plant too far apart.

Problem Diagnosis for Pumpkin

Problem	Probable cause	Comments
Deformed, curled leaves. Small, soft-bodied insects on underside of leaves. Sticky honeydew or black sooty mold may be present.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Fine stippling on leaves; yellow or brown leaves; leaf underside silver-gray with fine webbing and yellow, orange, or red dots.	spider mites	Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves turn yellow. Honeydew or sooty mold present. Clouds of tiny white insects fly up when plant is disturbed.	whiteflies	Remove infested plants as quickly as possible. Remove lower, infested leaves of plants that are not totally infested.
Coarse, white stippling on upper surface of leaves. Leaves may turn brown.	leafhoppers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Blotches or tunnels on leaves.	leafminers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Angular necrotic areas on leaves.	angular leafspot	Caused by a waterborne bacterium. Avoid wetting foliage with irrigation water.
Swelling, beads on roots. Wilted plants. Poor yields.	nematodes	Rotate crops. Use soil solarization.
Holes chewed in leaves. Scarring of runners, young fruit. Wilting. Beetles visible.	cucumber beetles	Beetles are yellow-green with black stripes or spots. Use pyrethrins.
Leaves have small specks that turn yellow, then brown. Vines wilt from point of attack to end of vine.	squash bug	Trap adults beneath boards in spring. Turn over boards in morning and kill bugs. Pick off adults, young, egg masses.
White, powdery spots on leaves and stems. Spots may enlarge and completely cover leaf. Defoliation may occur. Yields reduced.	powdery mildew	Spores of powdery mildew fungus are spread by wind and air currents. Disease is less severe in hot, dry weather. Plant resistant varieties. Remove old plant debris. Consult UC IPM Pest Notes or Flint 1998 for management options.
Yellow spots on upper leaf surfaces; grayish, fuzzy growth on undersides of spots.	downy mildew	Fungal disease. Plant resistant varieties. Remove old plant debris.
Stunted plants, small leaves with irregularly shaped light and dark spots (mottled). Yields reduced.	mosaic virus	Transmitted by aphids. Remove infected plants as soon as detected. Control aphids. Control weeds. Aluminum foil is effective as soil mulch to reduce infection. Deformed fruit is edible.
Poor fruit set	insufficient pollination; lack of bee pollinators	Hand-pollinate using artist's paintbrush if bee pollinators are too few. Bee activity may be low because of cool weather or insecticides.
Plants wilt and die, beginning with older crown leaves. Light brown streaks occur inside lower stem, runners, and root—visible when split lengthwise.	Verticillium wilt	Caused by soilborne fungus. Rotate crops. Avoid soil previously planted in potatoes, peppers, eggplant, tomatoes, or cucurbits.
Plants wilt suddenly. Roots rot.	sudden wilt	Caused by *Pythium* fungus. Avoid water stress after fruit set. Avoid wetting soil to the crown. Improve drainage. Plant on raised beds.
Water-soaked, sunken, brown or black spot on fruit not restricted to blossom end.	belly rot	Rotate crops. Improve drainage. Stake or cage to keep fruit off ground.
Excessive vegetative growth.	planting too close together	Increase plant spacing.

Note: Pumpkin *(Cucurbita pepo* var. *pepo)* is a relative of melons *(Cucumis melo)*, including cantaloupe, honeydew, and crenshaw; winter and summer squash *(Cucurbita pepo* var. *melopepo)*; cucumbers *(Cucumis sativus)*; and watermelon *(Citrullus lanatus)*. Collectively known as the cucurbits, they suffer from similar pests and diseases, as is evident from the problem diagnosis table above.

ground until the plant tops are dead, or nearly so, and the skin on the tubers is firm, not flaky. Then dig them up and store in a cool, dark place.

Pumpkin *(Cucurbita maxima, C. pepo)*

Recommended Varieties (Disease resistance, table 13.6)

- Spirit (semibush, multipurpose) (AAS)
- Autumn Gold (multipurpose, turns gold before maturity) (AAS)
- Jack O'Lantern (good for carving)
- Big Max (large fruit for showing)
- Bushkin (compact vine for large container or garden)
- Cinderella

Pumpkins can range in size from small jack-o'-lanterns to more than 100 pounds, depending on the variety grown and the culture provided. Pumpkins need ample space. The bush types can spread to more than 20 feet. Check table 13.2 for the best planting dates in your area. Give pumpkins the same care and treatment as described for winter squash. Keep leaves dry to prevent foliar wilt diseases.

To monogram a jack-o'-lantern, scratch a name into the fruit before the shell is hardened (usually in late August or early September). The inscription will callus over and become more distinguishable as the pumpkin matures.

Radish *(Raphanus sativus)*

Recommended Varieties (Disease resistance, table 13.6)

Red

- Cherry Belle (AAS)
- Champion(AAS)
- Scarlet Knight (F)

Multicolored

- Easter Egg Hybrid

White

- April Cross Hybrid (long, pungent Asian type)
- Icicle (tapered, mild)
- Snowbelle (round)

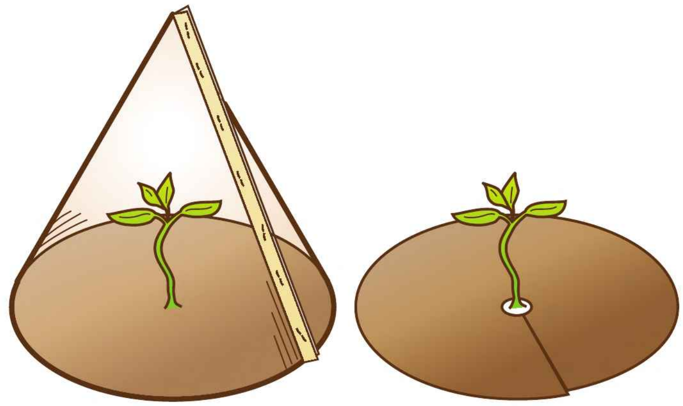
Radishes are easy to grow; in cool areas,

Problem Diagnosis for Radish

Problem	Probable cause	Comments
Roots fail to form.	crowded growing conditions	Thin early to correct.
Radishes "hot."	overmaturity; variety	Harvest at early stage. Some varieties are more pungent than others.
Small holes in leaves.	flea beetles; cucumber beetles	Flea beetles are small beetles, $^1/_{16}$ in long, that jump like fleas. Ignore problem if harvest is near. Consult UC IPM Pest Notes or Flint 1998 for management options.
Deformed foliage with whitish or yellowish spotting on leaves. Plants look wilted.	harlequin bug	Bugs are black with bright red, yellow, or orange markings, suck fluids from plant tissue. Handpick bugs and egg masses. Eliminate old, nonproductive cole crops, wild radish, and mustard because they provide breeding sources.
Small plants wilt and die. Grooves on surface of roots; winding tunnels through roots. Fleshy part may become streaked with brown from tunneling.	cabbage maggot; root maggot	Prevent infestation. No practical control when maggots occur on growing crop. Consult UC IPM Pest Notes or Flint 1998 for additional management options.
Leaves with light green areas and a violet-colored downy growth on undersides. Roots with black network inside.	downy mildew	Remove old plant debris. Rotate crops.

Figure 13.4

Two preventive devices for protecting plants from cabbage maggot. The cone-shaped screen cover on the left is constructed from standard window screen fixed to a wooden frame. It can protect plants until they grow big enough to tolerate damage. The screen cone covers can be stacked and stored for future use. Another device (right) is a 3-inch-(7.5 cm)-diameter disk of tarred paper, foam rubber, or other sturdy material placed flat around the base of each plant as it is transplanted. Cut a hole in the center of each disk for the transplant's stem. The disk prevents adult flies from laying eggs near plant stems and may also encourage the aggregation of predatory beetles that eat cabbage maggot eggs and larvae. Both devices and other management strategies are described in detail in *Pests of the Garden and Small Farm* (Flint 1998).



Problem Diagnosis for Rhubarb

See table 13.5 for general techniques for recognizing and managing common problems associated with rhubarb, such as aphids, flea beetles, and leafhoppers.

Problem Diagnosis for Rutabaga

As a member of the Brassica family, rutabagas are related to turnips, cabbage, cauliflower, kohlrabi, mustard greens, broccoli, and brussels sprouts. Rutabagas suffer from similar pest insects, diseases, and cultural problems that plague its relatives. See "Problem Diagnosis for Cabbage." Cabbage root maggot is an important pest problem for rutabagas.

you can plant several successive crops during the season. The crop is ready for harvest 3 to 6 weeks after seed are planted. Beware of overmaturity, which results in splits, cracks, hollowness, and pithy roots, as well as the development of a seed stalk.

Radish is classified as a cool-season crop. The best root shape and yield are produced at cool temperatures (50°–70°F) and relatively short days (10–12 hours). A number of environmental conditions can cause serious quality defects. One of the defects that often puzzles growers and gardeners is the lack of development of the edible part. The problem is known as thready root because the hypocotyl cells do not expand normally and everything belowground resembles a slender, often deformed taproot. Researchers have determined that temperatures in the range of 70° to 80°F and long day lengths produce more deformed and thready roots. Bolting is also promoted by high temperatures and long day lengths. If cabbage maggot is a problem, protect the plants as shown in figure 13.4.

Rhubarb *(Rheum rhabarbarum)*

Recommended Varieties

- Cherry Red (red stalks)
- Victoria (green stalks with red shading)
- Riverside Giant (green stalks)

Rhubarb is a cool-season perennial cultivated for its large leaf stalks (petioles). It grows best along the coast and in cool sections of the Central Valley. When grown in areas with hot summers, rhubarb will normally die or produce spindly, poor-quality leaf stalks, which are actually petioles. Perennial rhubarb production may not be successful in many areas of southern California or other areas where insufficient winter chilling occurs. Rhubarb can be grown as an annual in these zones by starting plants from seed in August, transplanting them to the garden when plants are 3 to 4 inches tall, and harvesting leaf stalks in the following spring. Keep the planting well watered and sidedress fertilizer three or four times during the production period, starting about 2 or 3 weeks after transplanting. The quality and quantity of annual rhubarb production may not be very high.

For perennial rhubarb, start plants in the winter or very early in the spring. It is common to grow rhubarb from a piece of an old plant (crown) or rootstock that consists of a fleshy rhizome, fibrous roots, and buds; be sure the crown has at least one good, strong bud. Plant crowns 3 to 6 inches below the soil surface in late win-

ter or spring. Keep the soil around plants evenly wet during the spring and summer and sidedress nitrogen fertilizer at least three times per year: when spring growth first starts, when harvest begins, and when harvest ends. Rhubarb grows vigorously into midsummer, then the crown gradually becomes dormant; several hours of temperatures below 40°F are required to stimulate bud break and regrowth.

During the first growing season, no leaf stalks should be harvested. Harvest should begin in the spring of the second and each succeeding year and end in early summer. Never harvest all the leaves. Several leaves should remain on the plant to support current and future production. Note that rhubarb leaf blades are poisonous and should never be eaten. Eat only the leaf stalks (petioles). Divide the plants and replant the new rootstocks periodically.

Rutabaga *(Brassica napus)*

Recommended Variety

American Purple Top

Rutabaga can be grown in cooler areas of the state and requires the same treatment as turnips. Prepare the soil as directed for carrots. Rutabagas require 90 to 100 days to grow into large yellow-fleshed roots, 3 to 6 inches in diameter. The top half of the root usually grows above the ground and may have a purple pigmentation. Do not leave rutabagas in the soil if freezing conditions are likely to occur.

When rutabagas reach the desired size, dig up the roots and trim, wash, and dry them. Eating quality is improved by a short storage period. Rutabagas are sometimes waxed and stored under cool, humid conditions. Rutabaga greens are edible, but they are not as good a source of greens as turnips.

Spinach *(Spinacia oleracea)*

Recommended Varieties (Disease resistance, table 13.6)

Melody Hybrid (AAS, DM, V)

America (AAS)

A cool climate is best for producing spinach. During periods of warm temperatures and long days, the leaves become tough, and plants are likely to produce seed stalks before making desirable foliage growth. Spinach is fast growing and short-lived and matures its leafy foliage in 7 weeks. It then quickly goes to seed, although it produces for a longer period in the cool, coastal areas before seed stalk development occurs. When the plant is

Problem Diagnosis for Spinach

Problem	Probable cause	Comments
Poor germination, emergence.	high soil temperatures	Plant at correct time.
Leaves partly or entirely consumed; light green caterpillars are visible.	loopers	Handpick, or *Bacillus thuringiensis* is effective.
Leaves become faded yellow.	aphids	Wash aphids from leaves before eating.
	inadequate nitrogen	Sidedress with nitrogen fertilizer.
Leaves have light green to yellow blotches. Pull back skin of blotch to find maggots in the mine.	leafminers	Pick off and destroy infested leaves.
Yellow to pale green areas on leaves; fluffy gray spores develop on undersurface of leaves after rain or heavy dew.	downy mildew	Problem when weather is wet and humid or under frequent sprinkling. Plant resistant varieties. Remove old plant debris. Rotate crops.
Plants begin to grow tall and send up flower stalks.	bolting	Caused by long daylight periods from late spring to early fall. Plant spinach in fall or early spring. Choose varieties carefully.

ready to harvest, either cut the entire plant or remove just the outer leaves. If you carefully cut the plant above the growing point, you can obtain a second crop.

New Zealand and Malabar are not true spinaches. New Zealand spinach *(Tetragonia tetragonoides)*, which forms short runners and resembles regular spinach in leaf shape, is frost-sensitive but tolerates warm weather much better than regular spinach. It is productive all season and can be cooked or used raw in salads, although the leaves are tougher than true spinach.

Squash, Summer *(Cucurbita pepo)*

Recommended Varieties (Disease resistance, table 13.6)

Scallop (pattypan)

- Peter Pan Hybrid (bush) (AAS)
- Sunburst (bright yellow) (AAS)
- Scallopini (bush) (AAS)
- Early White Bush (white)
- Trombocini or Zucchetta Rampicante

Yellow

- Early Prolific Straightneck (AAS)
- Sundance (crookneck, compact)
- Early Golden Summer Crookneck
- Dixie (crookneck, compact)

Zucchini

- Aristocrat (AAS)
- Greyzini (compact) (AAS)
- Ambassador (compact) (PM)
- Gold Rush (golden fruit) (AAS)
- Burpee Fordhook (AAS)

Summer squash grows on nonvining bushes. The many varieties have different fruit shapes and colors. The three main types include the yellow straight neck, or crookneck; the white, saucer-shaped, scallop, or pattypan; and the oblong, green, gray, or gold zucchini.

Squash plants have extensive root systems, so soil containing plenty of well-rotted compost or manure is ideal, although good crops may be grown in average soil that has been fertilized adequately. For extra-early fruit, plant seed in peat pots or other containers indoors or in hotbeds and transplant about 3 weeks later after danger of frost is past. Older plants that have hardened off and stopped growing do not transplant well and should be discarded. Squashes are warm-season plants and do not do well until soil and air temperatures are above 60°F.

Squash plants have separate male and female flowers on the same plant (monoecious). The male flowers do not produce fruit, but they do supply the pollen that fertilizes female flowers. Pollen must be transferred to the female flowers by bees for fruit to develop. If insecticides are necessary, use them late in the evening to avoid killing bees (see the sidebar “Fruit Set Problems in Squash, Melons, and Cucumbers”).

Seed or transplants can be planted through black plastic. Cover seed with 1 inch of soil. Under good growing conditions, summer squash is ready for first harvest 50 to 65 days after seed are planted. Zucchini types should be harvested when immature, about 6 to 8 inches long and 1½ to 2 inches in diameter; pattypan types, 3 to 4 inches in diameter; and yellow crookneck, 4 to 7 inches long. If the squash rind is too hard to be marked by a thumbnail, it is too old. Remove old fruit to allow new fruit to develop. It may be necessary to check plants daily for harvestable fruit once they begin to bear.

Squash, Winter (*Cucurbita pepo*, acorn; *Cucurbita maxima*, butternut)

Recommended Varieties (Disease resistance, table 13.6)

Acorn

- Table King (bush, strongly determinate) (AAS)
- Table Ace (semibush)
- Jersey Golden (semibush) (AAS)
- Sweet Mama (AAS, F)

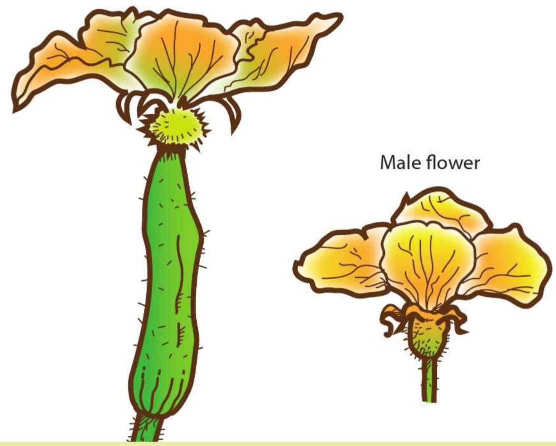


Figure 13.5

Squash flowers. *Source:* After Johnson 1981, p. 1.

Problem Diagnosis for Summer Squash

Summer squash (*Cucurbita pepo*) is a relative of winter squash (*Cucurbita pepo*); pumpkin (*Cucurbita pepo*); melons (*Cucumis melo*), including cantaloupe, honeydew, and crenshaw; cucumbers (*Cucumis sativus*); and watermelon (*Citrullus lanatus*). The cucurbits suffer from similar pests and diseases. See "Problem Diagnosis for Cucumber" in this chapter to understand how to diagnose the most common insect pests and diseases that attack summer squash.

Problem Diagnosis for Winter Squash

Winter and summer squash (*Cucurbita pepo*) are relatives of pumpkin (*Cucurbita pepo*); melons (*Cucumis melo*), including cantaloupe, honeydew, and crenshaw; cucumbers (*Cucumis sativus*); and watermelon (*Citrullus lanatus*). The cucurbits suffer from similar pests and diseases. See "Problem Diagnosis for Cucumber" to understand how to diagnose the most common insect pests and diseases that attack winter squash.

Fruit Set Problems in Squash, Melons, and Cucumbers

Squash, melons, and cucumbers belong to the family Cucurbitaceae, often called cucurbits, and they have a flowering habit unique among vegetable crops. They are monoecious; that is, they bear separate male and female flowers on the same plant. In order for fruit set to occur, pollen from the male flower must be transferred to the female flower. The pollen is sticky, so wind-blown pollination does not occur. Honey bees are the principal means by which pollen is transferred from the male to the female flower. Other insects cannot be depended on for pollination. Growers who produce these crops place hives of bees in their fields to ensure that pollination takes place. Wild honey bees are rare in some urban neighborhoods, and when bees are absent, fruit set on garden plants in the cucurbit family is very poor and often nonexistent. If only a few bees are present in the area, partial pollination may occur, resulting in misshapen fruit and low yield.

When no bees are present in the garden or the bee population is too low for good fruit set, the dedicated gardener can substitute for the bee by pollinating by hand. Hand-pollination is a tedious chore, but it is the only means of obtaining fruit set in the absence of bees. The pollen is yellow and is produced on the structure in the center of the male flower. You can use a small artist's paintbrush to transfer pollen, or you can break off a male flower, remove its petals to expose the pollen-bearing structure, and roll the pollen onto the stigma in the center of the female flower. When hand-pollinating, use only freshly opened flowers. Flowers open early in the morning and are receptive for only 1 day.

The female flower in cucurbits can be recognized easily by the presence of a miniature fruit (ovary) at the base of the flower (fig. 13.5). Female squash flowers are much larger than female melon or cucumber flowers. The male squash flower can be identified by its long, slender stem; the female squash flower is borne on a very short stem. In melons and cucumbers, male flowers have very short stems and are borne in clusters of three to five, whereas the female flowers are borne singly on somewhat longer stems.

Gardeners often become concerned when many flowers appear early but fruit fail to set. All of the early flowers are male. Female flowers develop somewhat later. In hybrid varieties of summer squash, however, the first flowers to appear are usually female, and these will fail to develop unless male squash flowers—and bees—are nearby.

A common misconception is that squash, melons, and cucumbers will cross-pollinate. This is not true: the female flowers of each can be fertilized only by pollen from that same species. Varieties within each species, however, will cross-pollinate. For example, zucchini squash will cross with crookneck or acorn squash. This is also true among varieties of cucumber and among varieties of cantaloupe. When more than one variety of a particular cucurbit is grown in the garden, they will readily cross-pollinate, and seed saved from these plants will produce fruit that will be different from either of the parents.

Butternut

Waltham (AAS)

Early Butternut (semibush) (AAS)

Burpee Butterbush (bush)

Winter squash varieties differ widely in shape and color. Bush-type plants require less space than creepers but often produce fewer fruit. Plant groups of 3 or 4 seed 2 to 4 feet apart in rows that are 6 feet apart. Spacing for bush varieties can be reduced by one-third to one-half. Once the plants emerge, thin to one plant per group. Plant when the soil has warmed up in the spring.

The mature fruit has a hard outer shell. Use a sharp knife to cut stems of fruit to be stored. Leave a short piece of the stem attached to the fruit and avoid bruising. Store in a dry, fairly cool location.

Tomatoes *(Lycopersicon esculentum)*

Recommended varieties and disease resistance

Home-grown tomatoes are one of the most popular garden vegetables. The varieties available to the home gardener are numerous, and the flavor and quality of home-grown, vine-ripened tomatoes are usually outstanding. Tomatoes require relatively little space for large production. Each tomato plant, properly cared for, can yield 10 to 15 pounds or more of fruit. Choose varieties bred for disease resistance for best results. Fusarium (F) and Verticillium (V) wilt are common diseases that can destroy a whole tomato crop. Many varieties are resistant to these two diseases. Look for VF after the cultivar name, indicating resistance to wilt. VFN means the plants are resistant to Verticillium, Fusarium, and nematodes; VFNT adds tobacco mosaic virus to the resistance list.

Tomato varieties are described as determinate or indeterminate. These terms refer to the plant growth habit. On determinate plants, the terminal shoots produce flower clusters that terminate the growth of the shoot on which they appear; thus, the plant growth gradually terminates after flowers form. Determinate tomato varieties have relatively short internodes, grow like a bush to a certain size (about 3 to 5 ft), set fruit, then gradually decline. They have a relatively concentrated harvest period. Most of the early-ripening and container tomato varieties are of the determinate type. Indeterminate tomato varieties produce large plants, tend to have longer internodes, and do not produce flowers on the terminal shoots; they continue to grow after flowering until frost or disease kills them and can produce fruit over an extended period. Many of the standard, large-fruited tomato varieties, as well as many cherry and grape varieties, are indeterminate types. Some large-fruit-producing varieties are termed semideterminate because they have a growth habit and fruit production period that is intermediate between indeterminate and determinate. All types of tomatoes require support of some kind to prevent the fruit from being in contact with the soil and thus being susceptible to rot. Supporting indeterminate and semideterminate plants also saves garden space and makes it easier to harvest fruit.

In addition to the usual round red tomato, home gardeners can choose to grow orange, yellow, pink, purple, or striped tomato varieties that have little commercial appeal and are available primarily to the home market. Some yellow varieties and others that are shaped like pears or plums have a mild, sweet flavor and are incorrectly referred to as low-acid tomatoes. In fact, the acid content of these varieties is very similar to others, but their sugar content is higher, which masks the acidity.

The large number of tomato varieties available may seem overwhelming to a new gardener; ask gardening friends for the names of their favorites. Varieties differ in plant size and habit, disease resistance, and climatic requirements. Although tomatoes are a warm-season crop, they can be grown in the cooler

areas of the state if you choose the right varieties.

Climate zones for tomato varieties

Listed below are three climatic zones (A, B, and C) and the tomato varieties that are adapted to those zones. Look for your climatic zone, then select the varieties you want. A number of heirloom and specialty varieties are also available if you wish to experiment with them.

Zone A

- coastal areas from Santa Barbara south
- coastal foothills and mountain ranges from San Diego through Marin Counties
- foothills surrounding the Central Valley
- Napa and Sonoma Valleys
- San Jose, Los Angeles, Santa Ana, and San Diego
- other areas where daytime summer temperatures are warm but usually below 95°F

Zone B

- inland valleys, high and low deserts, and other inland areas where daytime summer temperatures regularly exceed 95°F
- the Central, San Fernando, and San Gabriel Valleys
- Pomona, Riverside, and El Cajon
- interior valleys of San Diego County

Zone C

- immediate central and north coastal areas
- cool coastal valleys from Santa Maria north to the Oregon border, the San Francisco Peninsula, and areas with direct exposure to San Francisco Bay
- northern coastal foothills
- most mountains and mountain valley regions
- Eureka, Oakland, and Monterey
- Other areas with cool to moderate summers with evening temperatures frequently in the 45° to 55°F range

Small tomato varieties

Cherry tomatoes. Cherry tomatoes have small, cherry-sized (or a little larger) fruit that are often used in salads. They grow in all three zones of the state. Plants of cherry tomatoes range from dwarf size to 7-footers (Sweet 100). One standard cherry tomato plant is usually sufficient for a family, because they generally produce abundantly.

- Cherry Grande (medium-sized determinate plant, large cherry fruit) (VF, F, V)
- Sweet Cherry (large indeterminate plant, medium to large cherry fruit) (F)
- Sweet 100 (large indeterminate plant, clusters of small cherry fruit)
- Sungold (large indeterminate plant, clusters of orange cherry fruit)

Grape tomatoes. Grape tomatoes produce medium to large numbers of small, usually oblong, bite-sized fruit in clusters. They differ from cherry tomatoes in that they are smaller and have relatively thicker skin, lower water content, and higher sugar content. Introduced in the 1990s, they have gained steadily in popularity and can be grown successfully in all zones of the state.

- Jellybean
- Jolly
- Juliet
- Santa
- Ruby
- Tami G

Container varieties

Container varieties are adapted to all three zones of the state. Midget, patio, and dwarf tomato varieties have very compact vines and do best when grown in 5-gallon or larger containers or large hanging baskets. Some produce large fruit, but these are often of poorer quality than fruit from standard-sized plants. Container varieties are usually short-lived, producing their crop quickly over a short period.

- Patio (dwarf determinate plant, small to medium fruit) (F)

Problem Diagnosis for Tomato

Problem	Probable cause	Comments
Seedlings or small transplants with small holes in leaves. In severe cases, entire plant may be destroyed.	flea beetles	Rarely damaging except on seedlings. Tomatoes tolerate a lot of beetle damage if they are healthy.
Leaves almost totally eaten off of young plants. Small, dark weevils on plants.	vegetable weevil	Weevil attacks many vegetables but does not fly, so it spreads slowly through garden. Handpicking adults off plants at night is effective if population is low. Consult UC IPM Pest Notes or Flint 1998 for management options..
Lower leaves, stems have bronze, oily brown color. Discoloration moves higher on plant. Dry lower leaves drop from plant or plant may lose leaves.	tomato russet mite	Tiny mites not visible to naked eye; use 20× hand lens. Mites appear as slow-moving, whitish yellow, pear-shaped bodies. Do not grow tomatoes near petunias or any solanaceous plant such as potato because they are alternate hosts. Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves yellowish, slightly curled. Some leaves and fruit with small shiny spots; others may appear blackened. Clouds of small white insects fly up when plant is disturbed. Insects visible on undersides of leaves.	aphids	Tiny, oval, yellowish to greenish scalelike insects. Not a problem unless honeydew or sooty mold becomes obvious. Consult UC IPM Pest Notes or Flint 1998 for management options.
Plants with poor vigor, reduced yields. Foliage yellows, turns brown from bottom up. May look wilted. Many beads or swellings on roots.	root knot nematode	Nearly microscopic eelworms that attack feeder roots. Plant resistant varieties. Such varieties are labeled VFN (see text). Rotate crops. Remove old plant debris.
Tiny, white, winged insects on undersides of leaves.	whiteflies	Encourage beneficials.
Trails, tunnels in leaves.	leafminers	Consult UC IPM Pest Notes or Flint 1998 for management options.
Young plants cut off at ground.	cutworms	Use cutworm collars or registered insecticide.
Leaf veins turn purple and bronze. Leaves curl upward, feel thick, leathery, or brittle. Plant growth stops. Fruit ripen prematurely.	curly top virus	Spread by leafhoppers. After plants are infected, no practical control in the home garden. Purple leaves can also indicate phosphorus deficiency.
Leaves have irregular light and dark green pattern. May be wrinkled or frilly. Terminal growth may be spindly with narrow, wrinkled leaves.	tobacco mosaic virus	Plant resistant varieties (TMV). Do not handle plants more than necessary. Plant tomato seeds rather than transplants. Do not handle plants after smoking because TMV can be spread in tobacco. No cure for virus in infected plants. Infected plants produce edible fruit but yield, size, and quality are reduced.
Blossoms fall off.	night temperatures too low ($< 55°F$); day temperatures too high ($> 90°F$)	Hormone sprays can improve fruit set during low temperatures but will not help in high temperatures. Keep soil moderately moist.
	smog during blossoming period	Tapping on blossom stems 3 times/week at midday when flowers are open may help set fruit.
	excess nitrogen fertilizer	Fertilize properly.
	too much shade from trees, house	Plant tomatoes in full sun.
	early blossoms	Early blossoms often fail to set fruit consistently. Do not plant too early.
	wrong variety	Plant varieties that are adapted to California's hot summers.
Lower leaves yellow with tiny brown specks. Leaves die. Blossoms drop. Poor growth.	smog	Some varieties more susceptible than others. Very difficult to diagnose accurately.
Plants pale, turning yellowish with brown lesions on leaves. Brown stripes on some stems. Fruit poorly colored with circular light areas or distorted bumps. Plants eventually die.	spotted wilt virus	Spread by thrips from various crops, ornamentals, weeds. Remove and destroy infected plants. Control nearby weeds that can harbor virus or thrips vector.
Plants turn yellow, starting with one side or branch and gradually spreading. When cut off at base, main stem is dark reddish brown instead of normal ivory color. Plants wilt.	Fusarium wilt	Caused by a soil fungus that infects tomatoes only; favored by warm soil. Grow resistant varieties (F or VF). They are resistant to most (but not all) races of *Fusarium*.

Problem	Probable cause	Comments
Older leaves begin to yellow and eventually die. Yellowing begins between main veins of leaves. Internal stem is very slightly tan colored, usually in small patches.	Verticillium wilt	Caused by a soil fungus that infects many plants, favored by cool soil and air temperatures. Grow resistant varieties (V or VF). Avoid ground previously planted with tomatoes, potatoes, peppers, eggplant, or cucurbits. Symptoms most severe when plants are water stressed in hot weather with fruit load.
Plants grow slowly and wilt. Roots have water-soaked areas that turn brown and dry up.	Phytophthora root rot	Caused by a soil fungus. Most common in heavier clay soils. Irrigate affected plants carefully to maintain them. Do not saturate soil for extended periods; water more frequently for short periods.
Plants wilt with white cottony growth on stem near soil line.	southern blight	Caused by a fungus. Rotate to corn or other nonhost crops for 2 to 3 years.
Fruit turns light brown, leathery on side exposed to the sun.	sunscald	Caused by overexposure to sun. Maintain plant vigor to produce adequate leaf cover.
Water-soaked brown areas on leaves and stems. Grayish white fungus grows on undersides of leaves, and they die. Fruit discolored but firm.	late blight	Caused by a fungus. Favored by high humidity and temperatures around 68°F. Avoid sprinkler irrigation. Destroy all tomato and potato debris after harvest.
Irregular yellow blotches on leaves. Blotches turn brown and die, but leaves usually do not drop unless disease is severe. No symptoms on stem or fruit.	powdery mildew	Caused by a fungus. Usually occurs late in summer or fall but does not cause significant loss unless very severe so no control normally needed. Avoid water stress. Consult UC IPM Pest Notes or Flint 1998 for management options.
Dark brown to black blotches surrounded by yellowing along edges of leaves. Superficial dark specks on green fruit.	bacterial speck	Develops only under wet, cool temperatures, usually in early spring. Daily mean temperatures > 70°F suppress it. If speck is a problem, consider delaying planting until temperatures are warm. Rotate crops. Avoid overhead watering.
Worms up to 1 3/4 in long in immature or ripe tomatoes.	tomato fruitworm	*Bacillus thuringiensis* is somewhat effective. No control is needed unless infestation is severe.
Worms up to 3/8 in long tunneling in fruit.	potato tuberworm	Do not plant tomatoes where potatoes were planted the year before. Destroy volunteer potato plants.
Worms never longer than 1/4 in tunnel in core and fleshy parts radiating from core. Leaves may be mined and folded together.	tomato pinworm	Pinworm is most common in southern California and the central to southern end of the San Joaquin Valley. It occurs earlier in the season than fruitworm. Consult UC IPM Pest Notes or Flint 1998 for management options.
Leaves eaten, stems remain. Fruit with small to large gouged-out areas. Very large caterpillars may be present.	hornworms	Insects have distinctive horn on rear end. Handpicking and *Bacillus thuringiensis* are effective controls.
Fruit surface eaten away or fruit hollowed out.	snails, slugs	Snails feed on surface of fruit. Slugs hollow out fruit. Stake tomatoes to get fruit off ground and away from slugs and snails.
Creamy to yellowish cloudy spots lacking definite margin on ripe tomatoes. Tissue beneath spots is spongy.	stink bugs	Green to gray shield-shaped bugs 1/4 in long. Stink bugs overwinter beneath boards in weedy areas, refuse piles. Remove debris from garden area. Handpick egg masses and bugs. Control weeds.
Fruits are brown-black on bottom (blossom) end. Affects both green and ripe fruit.	blossom end rot	A physiological disease (not caused by a microorganism) that involves calcium nutrition and water balance in plant. Aggravated by high soil salt content or low soil moisture. More common on sandier soils. Maintain even soil moisture.
Fruit with large cracks in concentric circles around stem.	rainfall or irrigation, especially after dry spell	Remove ripe fruit immediately after a rain to prevent cracking.
Fruit with large cracks radiating from stem.	high temperatures (> 90°F); too much sunlight	Keep soil evenly moist. Maintain good leaf cover. In very hot regions, choose planting time to avoid fruit maturity when temperatures will consistently be above 90°F.
Fruit with black mold along growth cracks; develops on damaged, cracked tissue.	fruit rot	Prevent fruit cracking (see above). Handle fruit carefully.
Black, sunken spots on fruit.	Alternaria fruit rot	Consult UC IPM Pest Notes or Flint 1998 for management options.

Better Bush (compact determinate plant, small to medium fruit) (F, N, V)

Small Fry (compact determinate plant, small cherry fruit) (F, N, V)

Husky series (zones A, B, C; compact indeterminate plant that may need staking or caging; medium-small red-pink or gold fruit) (F, N, V),

Standard varieties

Many of the standard-sized tomato varieties listed below are indeterminate or semideterminate plants that require some type of support. Beefsteak-type tomatoes are large-fruited types, producing a tomato slice that easily covers a sandwich. A single fruit may weigh 2 pounds or more. These usually vary in their yield and are late to ripen, so plant some other standard-sized tomatoes for an earlier, consistent harvest.

Ace Hybrid (zones A, B; medium, determinate plant grown with short stake or cage or as a large bush; medium to large, attractive fruit) (N, V)

Better Boy (zone A; large, indeterminate plant grown with stake or cage) (F, N, V)

Big Beef (zones A, B; large, indeterminate plant grown with stake or cage; beefsteak-type fruit) (AAS, F, N, TMV, V)

Big Pick (zones A, B; large, indeterminate plant grown with stake or cage) (F, N, TMV, V)

Big Set (zones A, B; medium, semideterminate plant grown with cage or as a bush) (F, N, V)

Bingo (zones A, C; medium, determinate plant with large fruit grown with short stake or cage or as a bush) (F, TMV, V)

Carmelo (zone C; medium, semideterminate plant grown with cage or as a bush) (F, N, TMV, V)

Celebrity (zones A, B; medium, semideterminate plant grown with stake or cage; widely adapted, with consistently large, firm fruit) (AAS, F, N, TMV, V)

Champion (zones A, B, C; large, indeterminate plant grown with stake or cage; large, attractive fruit; excellent for winter crop in inland valleys) (F, N, TMV, V)

Early Bush 76 (zones A, B; medium, determinate plant grown with short stake or as large bush with concentrated production of large fruit; best determinate plant for zone A) (F, V)

Early Girl (zone A; large, indeterminate plant grown with stake or cage; continuous bearing of small to medium fruit) (V)

Early Pick (zones A, B, C; large, indeterminate plant grown with stake or cage; abundant medium to large attractive fruit) (F, V)

Floramerica (zones A, B; medium, determinate plant grown with short stake or cage; consistent yields of large fruit, some green shoulders) (AAS, F, V)

Jackpot (zones A, B; compact, determinate plant grown with short stake or as bush; concentrated production of medium to large fruit) (F, N, V)

Jet Star (zones A, B; large, indeterminate plant grown with stake or cage; good-quality medium to large fruit) (F, V)

Quick Pick (zone A; large, indeterminate plant grown with stake or cage; early, good-quality small to medium fruit (F, N, TMV, V)

Marvel Stripe (zones A, B; indeterminate plant grown with stake; yellow-red striped beefsteak-type fruit)

Royal Flush (zones A, B; compact, determinate plant grown with short stake or as a bush; concentrated production of large fruit) (F, N, V)

Supersteak (zone A; very large, indeterminate plant grown with stake or cage; large, high-quality fruit) (F, N, V)

Valerie (zones A, C; medium, determinate plant grown with short stake or as bush; early, medium fruit) (F, N, V)

Tomato culture

Start tomato plants indoors from seed or purchase transplants. If starting your own plants, use a light soil mix and give the plants plenty of natural or artificial light. The seed should be sown 6 to 8 weeks before the last frost date in your area.

When you are ready to plant, select stocky transplants about 6 to 8 inches tall. Set tomato transplants in the ground covering the stems so that only two or three sets of true leaves are exposed. Horizontal planting of tomato plants is an effective way to use leggy plants and make them stronger. Roots will form along the buried portion of the stem, giving better growth and less chance of plant injury from a stem that is too weak. Do not remove the containers if they are peat or paper pots. If nonbiodegradable containers are used, knock the plants out of the pots before transplanting and loosen the roots somewhat. Press the soil firmly around the transplant so that a slight depression is formed for holding water. Pour approximately 1 pint of starter solution or other dilute liquid fertilizer around each plant.

Keep the soil around new transplants moist for the first 3 to 4 weeks. Water established plants to about 2 to 3 inches deep when the soil dries. Apply enough water to wet the root zone thoroughly. Since weather and the depth of rooting vary, the right interval for applying water in the summer can vary from one to three times a week to once every 10 days or 2 weeks. Plants are best irrigated by using soaker hoses, drip irrigation, or another means that applies water slowly without wetting the foliage.

Sidedress plants with nitrogen fertilizer when they set their first fruit and every 4 to 6 weeks thereafter. Always water well after applying fertilizer. If some form of manure was used at planting, reduce the fertilizer rate by one-half. Applying relatively high amounts of nitrogen from organic or chemical sources before plants begin setting fruit causes plants to grow lush, leafy growth and significantly delays flowering and fruit set. It usually takes 10 to 12 weeks from the time transplants are set in the garden to have the first ripe tomatoes.

Supporting tomato plants off the ground reduces fruit rot, makes pest management easier, provides easier harvesting, and allows more plants to be grown in the same space. There are three common methods of supporting tomatoes. One method is to drive sturdy wooden stakes, 6 feet long by 1 to 1½ inches wide, into the ground about 1 foot deep and spaced 3 to 4 feet apart within the row. Twist and loop heavy twine tautly from stake to stake across plants at intervals of 10 to 12 inches up the stakes as plants grow. This creates a loose net that keeps plants upright in a solid row that is about 18 to 24 inches wide.

Another method is to tie plants individually to a fence or a wooden stake 5 to 6 feet tall. As plants grow, pull the stems toward the fence or stake and loosely tie them at intervals of 10 or 12 inches using a flexible material, such as strips of cloth. Plants supported in this manner often require pruning or pinching out of some shoots, or "suckers," from the main stem to keep the plants from becoming too heavy and large for their support.

Using a heavy-gauge metal cage is a third alternative, and one that requires the least amount of work. Cylindrical cages about 18 to 30 inches in diameter and 4 to 5 feet tall are set over each plant, and no tying or pruning is needed. Use concrete reinforcing wire or similar heavy-duty material with at least 6-inch spacing between wires so that plant stems can easily grow through them and you can get your hand inside to harvest the tomatoes. Caged tomatoes develop a heavy foliage cover, reducing sunscald on fruit.

Harvest tomatoes when they are red-ripe for best quality. Toward the end of the season, some whitish green, full-sized tomatoes will probably still be on the vines. You can pick these tomatoes and store them at 70°F to ripen. Picked tomatoes should be placed in the shade; light is not necessary for ripening immature tomatoes. Ripe tomatoes should be stored at 55° to 70°F to maintain their fresh, ripe flavor. Lengthy refrigeration causes fruit to lose flavor.

Tomato fruit set failure and flower drop

Most people who raise backyard tomatoes have experienced the problem of poor fruit set. Under good environmental conditions, fruit set occurs normally; yet tomato plants may fail to set fruit for any one of several reasons. The most frequent problems are

- cold nights in the spring
- high temperatures in the summer
- low light intensity
- smog (ozone)

The tomato flower contains both male and female parts (a "perfect" flower). In order for fruit set to occur, viable pollen from the anthers (male parts) must be transferred to the stigma (part of the female organs), germinate there, and send its tube down through the style to fertilize the ovules. When fertilized successfully, the developing ovules (young seed) produce a stimulus that results in fruit enlargement. Under adverse environmental conditions, one or more of these processes may fail to occur, and the flowers will fall from the plant. Occasionally, fruit enlarges without pollination or fertilization, but these are usually poorly formed and fail to develop to desirable size.

Prevention and control of fruit drop

Cool nights. After several days of nighttime temperatures below 55°F, fruit set often fails in most varieties. Under these conditions, fruit set can sometimes be improved with the use of fruit-setting hormones available in retail nurseries or agricultural supply houses. Research has shown that 4-CPA (parachlorophenoxyacetic acid) is more effective than BNOA (beta naphthoxyacetic acid). Follow label directions carefully.

Hot days. Fruit set failure in tomato also often occurs when daytime temperatures consistently exceed 90°F. Some varieties are more tolerant of high temperatures and continue to set fruit when others fail. Under these conditions, it is helpful to keep the plants in a healthy growing condition so that developing flowers will have a better chance to survive. Maintain a constant moisture supply, eliminate damaging insects, and control diseases. Fruit-setting hormones are not effective in hot weather.

Low light intensity. Tomato flowers may also fail to develop into fruit when sunlight is inadequate. This may occur when plants are growing under dense shade trees or along the north wall of a building. Avoid planting locations that do not allow several hours of direct sunlight per day. Best growth results where plants receive full sunlight throughout the day.

Smog. Research has shown that high concentrations of ozone, a principal air pollutant during summer months, significantly reduces fruit set in tomatoes. At present there is no solution for this problem.

Solar yellowing in tomatoes

Yellow discoloration in tomatoes occurs in the late spring under greenhouse conditions, or from late spring through the summer in the open field in inland areas where daytime temperatures regularly exceed 85°F. An accurate term for this condition is *solar yellowing* because the source of the problem is the sun. The cause of the problem is not only heat, but also high light intensity. This was shown by Dr. Werner Lipton, who coined the term *solar yellowing* in research he conducted on the subject in 1970. His treatments involved shading or painting the fruit either black or white. Black-painted fruit were higher in temperature than exposed fruit, but discoloration was highest in the exposed fruit. His conclusion was that short-wave radiation was largely responsible for defective coloration.

The reason for the yellow or yellow-orange color, rather than the normal red, is that the red pigment (lycopene) fails to form above 86°F. This phenomenon was first described by researchers in 1952 and was later confirmed by others. When lycopene fails to form, only carotenes remain for fruit color. In the field, some red color forms when day temperatures rise above 85°F because of fluctuation in noninhibiting temperatures during other parts of the day or night; in this situation, an orangey

red color results. In production areas where temperatures do not exceed 85°F, much redder color develops.

To develop a uniform red color in tomatoes, protect fruit from high temperatures and from short-wave radiation in areas of high light intensity. Dr. Lipton showed that sprays of nonphytotoxic whitewash are helpful. In greenhouses, growers who intend to mature fruit in May and June should begin to alter their pruning practices in March by allowing two leaves to develop on axillary branches instead of following the standard practice of removing these branches.

Green shoulders on fruit

The presence of green shoulders on mature tomatoes that are otherwise red is normal in some varieties, especially some heirloom varieties. Temperatures greater than 90°F while fruit are maturing can exacerbate green shoulders in varieties prone to the characteristic. Varieties that turn evenly red when fully ripe possess a gene for uniform ripening.

Blossom end rot

Blossom end rot is the name of a disorder in which a dark brown to black, leathery, sunken area appears on the bottom of tomato fruit. It may occur more readily in some years and in some varieties than others. The disorder occurs when plants are water stressed while the fruit are developing. A calcium deficiency can make the problem worse. Providing regular irrigation to keep plants well watered as fruit develop after fruit set can prevent the problem. Differences in varieties' tolerance of water stress, variations in weather from year to year, and disparities in water practices are the likely reasons for the inconsistent appearance of the problem. Affected fruit are edible, though a considerable portion of a fruit must be cut away to remove the leathery area.

Leaf roll of tomato

Leaf roll of tomato is a very common disorder in many tomato varieties grown in California. Leaf roll does not develop markedly on plants until about the time of fruit setting on the first and second flower clusters. At this time, the older leaves begin to roll upward and inward rather suddenly. Affected leaves are stiff to the touch, brittle, and at times almost leathery. They are much thicker than normal leaves and are shiny on both the upper and lower surfaces. In mild cases, leaves become trough shaped; in severe cases, the leaves may form a very tight cylinder, with the leaf margins touching or overlapping. The severity of leaf roll varies with climatic conditions, cultural practices, and the particular variety grown. No pathogens have been identified as causal agents. When leaf roll is severe, three-fourths of the leaves on a plant may be involved, exposing fruit to full sunlight and resulting in the development of disorders such as yellow leaf discoloration and sunscald.

No control methods for leaf roll are recommended because it is not known to severely damage plants or fruit production and its cause is not fully understood. Susceptible varieties have been observed to express leaf roll most frequently when they are grown in staked culture and heavily pruned. Maintaining a high soil moisture content for prolonged periods of time is also believed to promote the disorder.

Observations of an experiment in Florida led to a hypothesis that leaf roll might be caused by an accumulation of excess amounts of carbohydrates (sugars and starch). This theory was tested in the Floradel variety by removing vegetative shoots, flowers, and developing fruit, which serve as sinks for photosynthates. These treatments resulted in rapid expression of leaf roll, completely to the tops of certain plants. A second test involved growing plants under 0 to 75% shade to inhibit photosynthate production. Under high shade conditions, the incidence of leaf roll was reduced to less than 50%. In the experiment leaves that originally were shaded and did not roll

later developed leaf roll when exposed to full sunlight.

Although no definite conclusions can be drawn as to the cause-effect relationships of plant carbohydrate concentration to leaf roll, it does appear that leaf roll is most severe when tomatoes are grown in staked culture under high light intensity and high soil moisture.

Turnip *(Brassica campestris* var. *rapifera)*

Recommended Varieties (Disease resistance, table 13.6)

- Purple Top White Globe (pure white root) (AAS)
- Tokyo Cross Hybrid (for greens only)
- Seven Top (for greens only, large smooth leaves)
- All Top Hybrid

Turnips are grown for the tops and also for the enlarged root. The crop may be produced within 60 days. Turnips grow best in a cool climate, where both a spring and a fall crop are possible. The cultural practices for varieties used specifically for the production of greens are similar to those for growing table beets.

Watermelon *(Citrullus lanatus)*

Recommended Varieties (Disease resistance, table 13.6)

Bush vine

- Garden Baby (small, round fruit)
- Bush Charleston Gray (small, oblong fruit) (F)
- Bush Jubilee (small, oblong fruit) (AN, F)
- Bush Sugar Baby (small, round fruit)

Large vine

- Calsweet (large, oblong fruit) (F)
- Crimson Sweet (large, round fruit) (AN, F)
- Sugar Baby (small, round fruit)
- Sweet Baby (small, round fruit) (F)
- Charleston Gray (large, oblong fruit) (AN, F)
- Prince Charles (large, oblong fruit) (F)

Problem Diagnosis for Turnip

Problem	Probable cause	Comments
Distortion, stunting, wilting of plant. Soft-bodied insects in colonies on undersides of leaves.	aphids	Consult UC IPM Pest Notes or Flint 1998 for management options.
Holes in leaves. Chewing injury on buds or roots. Some plants may be cut off at soil level, much like cutworm damage.	vegetable weevil	Damage is spotty. Adults do not fly, so infestation of new areas takes place slowly.
Irregular holes in leaves. Small or seedling plants may be destroyed.	caterpillars of cabbage looper; imported cabbage worm; armyworms	Handpick. Depending on the specific pest, *Bacillus thuringiensis* is somewhat to very effective.
Deformed leaves with whitish or yellowish spotting. Plants may have wilted appearance.	harlequin bug	Attractive, shield-shaped insects usually black with bright red, yellow, or orange markings. Injury is caused by bugs sucking fluids from tissues. Handpick the bugs and their egg masses. Eliminate old, nonproductive cole crops, wild radish, and mustard because they are breeding sources.
Feeding injury (engraving) on root surface or tunneling through roots of young plants or seedlings, which fail to grow properly. Plants may wilt or die.	cabbage maggot (root maggot)	All control measures are preventative. No practical control after maggots occur on the growing crop. Consult UC IPM Pest Notes or Flint 1998 for additional management options.

Problem Diagnosis for Watermelon

See “Problem Diagnosis for Cantaloupe.” *Note*: Watermelon *(Citrullus lanatus)* is a relative of melons *(Cucumis melo)*, including cantaloupe, honeydew, crenshaw; winter and summer squash *(Cucurbita pepo)*; pumpkin *(Cucurbita pepo)*; and cucumbers *(Cucumis sativus)*. Collectively, known as the cucurbits, they suffer from similar pests and diseases, evident from the problem diagnosis table above.

Seedless

Triple Sweet Hybrid

Tri X-313 Hybrid

Firecracker

Yellow-fleshed fruit

Yellow Baby (small, round fruit) (AAS)

Yellow Doll (small, round fruit; semi-compact vines)

You need a fairly large garden to grow watermelons successfully. The general methods of planting and handling are the same as those given for growing cantaloupes, their cucurbit relatives. The first fruit may be ready for harvest about 90 days after the seed are planted. In areas where winter rainfall is over 12 inches and the soil stores 9 inches of water, watermelons grow reasonably well with little irrigation, although irrigation increases yields. If you plan to provide limited irrigation, plant seed as early as possible in the spring and thin the plants to one plant per hill. If plants are stressed for water when they start to set fruit, melons will be small and yields reduced.

To test melons for ripeness, rap the side of the fruit with your knuckles. A light or metallic sound means that the fruit is still green; a dull sound means that it is ripe. This is most reliable in the early morning. During the heat of the day or after melons have been picked for some time, they all sound ripe. Fruits have a “ground spot” where they rest on the ground. The ground spot goes from white or beige to dark yellow as the fruit matures, depending on the variety and moisture presence at the contact surface with the fruit. If fruit are grown on plastic mulch, the ground spot rarely turns yellow. Watermelons tend to become rough as they mature. The tendrils closest to the fruit usually darken and dry up as the fruit ripens, although some seedless types keep a green tendril when they are ripe. Do not pull melons off the vine; cut the vines with a sharp knife.

For information on fruit set problems, see “Fruit Set Problems in Squash, Melons, and Cucumbers” in the section on summer squash. Watermelon is a relative of cantaloupe, honeydew, and crenshaw melons; winter and summer squash; pumpkin; and cucumber. Collectively known as the cucurbits, they suffer from similar pests and diseases.

Herbs

Many culinary herbs—the herbs used to season food—are very easy to grow, and a bountiful harvest can be secured with a minimum of care. A few plants of each kind of herb add color and fragrance to the garden and provide an adequate supply for the average family.

Growth

Depending on the species, variety, and life cycle, herbs are divided into three groups. Annual herbs include such plants as anise, basil, coriander, and dill; biennial herbs include caraway and sage; and perennial herbs include chives, fennel, lovage, marjoram, mint, and thyme. In California’s mild climate, some tender perennial herbs do quite well, whereas in colder climates, they grow as annuals. For both annuals and perennials, spring is the usual season to plant herbs.

Table 13.7 summarizes basic information about many common annual and perennial herbs grown in the home garden. When planning an herb garden, factor in the growth habit of the individual herbs. Perennial herbs are best planted around the edges of the garden or in the flower border, if they are also ornamental. Plant the taller herbs in the background, with lower ones in front, near walks and paths. A large number of herbs may be set either in beds or in rows for ease of irrigation and cultivation. Small-sized herbs, such as chives, basil, sweet marjoram, peppermint, rosemary, summer savory, and thyme, adapt to culture in pots or other containers that are 6 inches in diameter or larger.

In the garden, group herbs according to their light requirements (full sun or partial shade), and choose a soil that is well drained and loamy for best results. Herbs prefer a soil pH of about 6.0 to 7.0. Prepare

Table 13.7.

USE AND CULTURE OF CULINARY HERBS

Common name	Scientific name	Spacing (in)			Propagation	Cultural hints	Uses
		Height	Row	Plants			
Annual herbs							
anise	*Pimpinella anisum*	24	18	10	seed	Plant in spring.	Leaves used for seasoning, garnish; dried seed used as flavoring in cakes, etc.
basil, sweet	*Ocimum basilicum, O. minimum*	20–24	18	12	seed	Plant in spring. Pinch tips and flowers to favor leaves.	Seasoning for soups, stews, salads, sauces, omelets. Decorative when grown in containers.
borage	*Borago officinalis*	24	18	12	seed	Best in dry, cool, sunny areas.	Young leaves used in salads. Leaf tips and flowers used in summer drinks. Flowers candied.
caraway*	*Carun carvi*	12–24	18	10	seed	Biennial seed bearer.	Flavoring, especially in bakery items (bread, cake) and cheese; young leaves in salads, soups.
chervil	*Anethum graveolens*	10	15	3–6	seed	Sow in early spring or fall. Partial shade best.	Aromatic leaves used in soups and salads and for garnish, like parsley. Tastes like mild anise.
coriander (cilantro)	*Coriandrum sativum*	24	24	18	seed	Sow in early spring or fall.	Seed used in confections, curry; leaves in salad. Leaves, known as cilantro, used in Mexican, Asian, and Mediterranean dishes.
dill	*Anethum graveolens*	24–36			seed	Sow in early spring.	Young leaves used in salads, seed in flavoring, especially for pickles.
fennel, Florence fennel	*Finocchio foeniculum, Foeniculum officianalis*	18–60	18–30	6–12	seed	Sow in early spring. See earlier discussion on fennel.	Has mild anise-like flavor; seed used in soups, breads. Leaf stalk and stem base eaten raw or braised; leaves for garnish. A primary ingredient in absinthe.
parsley*	*Petroselinum crispum*	5	18	6	seed	Slow to germinate. Needs some shade. Soak seed in water to improve germination.	Brings out flavor of other herbs. Leaves used for garnish and in salads. Fine base and seasoning. Popular, but only a few plants are needed in the home garden. Types include curly (French) and flat leaved (Italian).
summer savory	*Satureia hortensis*	18	18	18	seed	Sow in spring.	Use leaves fresh or dry for salads, dressings, stews. Adds peppery flavor.
Perennial herbs							
catnip	*Nepeta cataria*	36–48	24	18	seed or division	Invasive.	Leaves for tea and seasoning.
chives	*Allium schoenoprasum*	12	12	12	seed or division	Plant anytime but best in spring.	Favorite of chefs. Snip tops finely. Good indoor potted plant. Leaves used in omelets, salads, soups.
horehound	*Marribium vulgare*	24	18	15	seed, cuttings, division	Grow in light soil. Perennial.	Leaves used in candy or as seasoning.
hyssop	*Hyssopus officinalis*	24	18	15	seed	Tolerates wide range of conditions.	A mint with highly aromatic, pungent leaves.

Table 13.7. cont.

USE AND CULTURE OF CULINARY HERBS

Common name	Scientific name	Spacing (in) Height	Row	Plants	Propagation	Cultural hints	Uses
lavender	*Lavandula vera*	24	18	18	cuttings, division	Grows in dry, rocky, sunny locations. Divide in spring, take cuttings in spring or late summer.	Fresh in salads; use flowers dried for sachets, potpourri.
lovage	*Levisticum officinale*	36–48	30	30	seed	Rich, moist soil. Plant in late summer.	Of the carrot family; cultivated in European gardens as a domestic remedy.
oregano	*Origanum vulgare*	24	18	9	seed, division	Cut back flowers. Good in containers.	Flavoring for tomato dishes, pasta, pizza. Leaves used in soups, roasts, stews, salad dressings.
marjoram, wild marjoram	*Origanum majorana*	24	18	9	seed, division	Cut back flowers. Good in containers.	Flavoring for tomato dishes, pasta, pizza. Leaves used in soups, roasts, stews, salad dressings.
peppermint	*Mentha piperata*	36	24	18	seed, cuttings division	Cut before it goes to seed.	Aromatic; multiple uses as flavoring. Oil used in products such as chewing gum, liqueurs, toilet water, soaps, candy.
rosemary	*Rosmarinus officinalis*	36–72	18	12	cuttings, seed	Sow in spring.	Leaves flavor sauces, meats, soups, preserves, sweet pickles. One plant is enough for home garden. Can be grown indoors in containers.
saffron	*Crocus sativus*	10			bulbs, division	Plant bulbs in early fall, 3–4 in deep. Replant every few years.	Stigmas of flowers dried, used to color butter, cheese. Used to flavor creams, sauces, preserves.
sage	*Salvia officinalis*	18	24	12	seed, cuttings	Grows slowly. Renew bed every 3–4 years.	Seasoning for meats, herb teas. Use fresh or dried.
spearmint	*Mentha spicata*	18	24	18	cuttings, division	Invasive.	Aromatic; for flavoring, condiments, teas.
sweet marjoram	*Majorana hortensis*	12	18	12	seed, cuttings	Overwinters as potted plant. Often grown as annual. Harvest before plant blooms.	Seasoning, fresh or dried. Fresh leaves used in salads. Dried leaves used to season meat, cheese, etc. Tastes like sweet oregano relative.
sweet woodruff	*Asperula adorata, Galium odoratum*	8	18	12	division, seed	Keep indoors in cold winter period.	Flavoring in drinks.
tarragon	*Artemisia dracunculus*	24	24	24	division, root cuttings	Protect in cold winters.	European herb of aster family; aromatic seasoning. Leaves, tips used in dressings, tartar sauce, vinegar, preserves. Chopped leaves used in salads.
thyme	*Thymus vulgaris*	8–12	18	12	seed, division, rooted tip cuttings	Start new plants every 3–4 years. Rooted tips in early spring are practical propagation method.	Aromatic foliage for seasoning meats, soups, dressings.
winter savory	*Satureia montana*	24	15	18	seed, cuttings	Trim out dead wood.	Seasoning for stuffing, eggs, sausage; accents strong flavors; more pungent than summer savory.

Note: *Biennial.

the soil to a depth of 8 inches and incorporate an organic amendment if the soil is not loamy. Give perennial herbs an area that will not be disturbed by tilling. Herbs such as mint that spread by runners should be given a large area or be planted in containers to provide some control. Mint spreads rapidly, and parsley and fennel seed themselves, so they can become nuisances in the garden.

Herbs may be propagated from seed, rooted cuttings, or division of a mother plant. Many common herbs are available as small transplants at nurseries and garden centers. Seeds may be started either indoors or outdoors. The easiest method is to sow them directly into peat pots or other small containers about 6 weeks before the last expected frost.

Perennials may be started from seed, division, or cuttings. Root cuttings in flats or containers should be covered with plastic to maintain high humidity. A satisfactory rooting medium can be made from 4 to 5 inches of clean, coarse sand. Keep the sand moist, and keep plants out of direct sunlight when young. In 4 to 6 weeks or when cuttings are rooted, move them to pots or plant in the garden.

Transplant all herb plants after danger of severe frost is past. Control weeds during the growing season to prevent competition for water and nutrients. A light mulch conserves soil moisture and helps control weeds. Irrigation will be necessary for most herbs, although once established, many perennial herbs tolerate some drought. Fertilize herbs according to the guidelines discussed in this chapter in the sections “Fertilizing before Planting” and “Caring for Your Vegetable Crop.”

Harvesting

Herb leaves that are used fresh may be picked whenever the plant has enough foliage to maintain continued growth. Pick herbs for drying just before the flowers open, when the leaves contain the highest content of aromatic volatile oils. Select and cut stems individually about 6 inches below the flower buds. Remove dead or damaged leaves and cleanse dirty leaves by rinsing them gently in cold water and drying them with paper towels. Plants may also be sprayed with a garden hose the day before harvesting. Discontinue harvesting leaves of perennials in late summer to allow the plants to store enough carbohydrates for overwintering and renewing growth next season.

You may save seeds for culinary uses or for starting plants the next year by allowing the plants to mature and flower. Harvest seeds when they change from green to brown or gray and allow them to dry thoroughly before storing.

Drying and storage

Herbs may be dried by tying the cut stems in small bunches and hanging them in a well-ventilated, low-dust, darkened room. Each bunch should be labeled, because many dried herbs are very similar in appearance. The herbs will dry properly if leaves are dried rapidly without artificial heat or exposure to sunlight. However, in the case of plants with thick, succulent leaves, such as basil, rapid drying in an oven, dehydrator, or solar dryer may be the best method to retain color and maximum aromatic quality. If leaves are not too small, they may be removed from the stems and dried in a single layer on trays made of window screening or ¼-inch mesh hardware cloth. Label each herb. Stir the leaves gently once or twice a day to speed drying.

When drying is complete, remove the leaves from the stems or trays and place them in sealed glass jars in a warm place for a week. At the end of that time, examine the jars to determine whether any moisture has condensed on the inside of the glass. If there is condensation, remove the contents and spread them out for further drying. If necessary, the final drying may be completed by spreading the leaves on a cookie sheet in an oven at 110°F or less. Herb leaves are dry when they become brittle and will crumble into powder when rubbed between the hands. If you prefer to

use herbs in powdered or ground form, crush the leaves with a rolling pin, pass them through a fine sieve, or grind them in a blender or with a mortar and pestle.

Store herbs in airtight bottles, preferably brown glass, in a cool place out of direct sunlight. Using airtight containers allows the herbs to retain their essential oils and flavors.

Herbs as potted house or patio plants

Most small herb plants may be grown in 6-inch or larger pots. When given loving care in a sunny window, they will supply sprigs for culinary use throughout the year. If an enclosed porch or sunroom is available, larger herbs may be grown. Containerized herbs may be grown on a patio during the summer in all areas and year-round where mild winters are common. Some of the best to try are basil, sweet marjoram, oregano, rosemary, thyme, and bay laurel. Start potted plants from seed, cuttings, or divisions in midsummer, or, if available, purchase transplants. When making cuttings or divisions, be sure to hose off any insects or eggs that might be present.

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Grapes 14

Pamela M. Geisel, Paul M. Vossen, and
Delbert S. Farnham

Learning Objectives

Understand the basic cultural practices for growing table or wine grapes in the home garden in California.

Learn which cultivars of grapes are suited best to different climates in California.

Become acquainted with some of the major pests of grapes in the home garden and learn basic information on how to control them.

Grapes

Grapes have been cultivated since ancient times. The Mission padres introduced the Mission cultivar of grapes to California from Spain via Mexico, but this cultivar was not well adapted for producing raisins, quality wine, juice, jelly, or fresh fruit for eating. Other European grape cultivars, brought to California in the nineteenth century, have provided the basis for today's thriving grape industry. Today home gardeners still grow some very old European cultivars, such as Muscat of Alexandria and Thompson Seedless. Plant breeders have also developed some outstanding modern cultivars, such as Flame Seedless and Perlette. Three species of grapes are commonly grown, each with many different cultivars:

- *Vitis labrusca*, an American species with cultivars such as Concord and Niagara.
- *Vitis vinifera*, a European species whose numerous cultivars dominate California's wine, table, and raisin industries.
- Hybrid crosses of European and American species.

Generally, American types are more cold-hardy than European types. The two types also differ in their fruit characteristics and growth habits. European cultivars generally require a longer growing season to mature their fruit, although most grape cultivars need some summer heat to produce good-quality fruit.

Site Selection

Grapes require full sunlight for optimal production and vine vigor. If planted in rows, they should ideally run north to south to maximize light penetration into the canopy, but row direction is not critical for home grape growing.

Soil Requirements

Grapes can grow on a wide range of California soil. Avoid soil with poor drainage or a high water table. Use raised beds to provide an adequate root zone if vines are to be grown on soil with hardpan or claypan, or if shallow soil is located on top of impervious bedrock. Grapes grow satisfactorily on poor, shallow soil as long as irrigation is available. A slightly acidic pH range from 5.5 to 6.5 is preferred, though not required.

Spacing

Vine spacing should be determined based on general plant vigor. Vigorous vines should be spaced farther apart than less vigorous cultivars. For example, Black Monukka, an excellent home garden seedless table grape, usually requires wider spacing than the less vigorous Emperor cultivar. Soil type, fertilization, and irrigation practices contribute significantly to plant vigor. Spacing between rows can be up to 12 feet, with 8 feet between vines within the row. Some form of trellising and training are necessary, as discussed later in this chapter.

Selecting Plants

Plant healthy 1-year-old bare-root vines available from retail nurseries. Cuttings may also be collected from healthy vines and planted directly where the vine is to grow permanently. Because bare-root vines and cuttings dry out very quickly, plant them immediately after purchase. As a general rule, plant at the same depth as the rooted plants grew in the nursery.

Cuttings should be 16 to 20 inches long and have several buds. Prior to planting, use a knife to remove any buds that will be belowground. This will prevent any sucker growth from developing from buried buds. Generally, only the upper two buds should be retained on each cutting and exposed aboveground at planting.

Rootstocks

Rootstocks are appropriate in areas where grapes cannot be grown on their own roots because of nematode and grape phylloxera infestation, or in old vineyard areas that are being replanted. Several rootstocks are nematode resistant and possess moderate phylloxera resistance. The cultivars used most frequently as rootstocks are Freedom and Harmony. In coastal areas, one of the following phylloxera-resistant rootstocks should be used: SO4, 5BB, 110R, 99R, or St. George.

Cultivars for the Home Garden

A large number of grape cultivars are recommended for the home garden in California. Cultivars are divided into raisin, table, and wine grapes according to their primary use. Some are suitable for multiple uses, including making juices or jellies. American cultivars and American hybrids are typically grown for table grapes, juice, or jelly and are less commonly dried to make raisins.

Table grape and multiple-use cultivars are most commonly grown by home gardeners. They are usually adapted to a range of climatic conditions and training systems. Numerous cultivars are available, and suitable ones for various climate zones are listed in tables 14.1 and 14.2. Table grapes are often seedless, with a tender skin. They are typically harvested when they develop adequate sugar content with relatively low acidity.

Wine grape cultivars are suitable for many home gardens, but for optimal performance, the cultivar chosen should be suited to the climatic region and site. Table 14.3 provides cultivar information on wine grapes. Wine cultivars generally differ from table cultivars by their relatively small berry size, presence of seeds, softer berry texture, relatively high acid content (even though they are harvested at a higher sugar content than table cultivars), and tough skin, factors that make them less desirable for fresh eating.

Growth Pattern and Growth Cycle

As with most fruits, the grape must bloom and the flowers be pollinated before the berries (fruit) begin to develop. Grape flower clusters begin their differentiation and development in dormant buds during the summer before the year that grapes are actually harvested. Flower differentiation is completed during that fall by the time the vines lose their leaves. After dormancy and bud burst, grape shoots begin to grow rapidly. When shoots reach 4 to 6 inches long, grape flower clusters can be distinguished, and by 12 inches, the flower clusters are well separated on the growing shoot. The development of flower clusters on the emerging shoots usually starts in mid-March, and the flowers typically begin to bloom in May. Grape flowers have a protective cap, known as a calyptra, that covers the male and female sex organs until bloom, when it cracks open from the bottom and exposes the flower parts to pollination, which must occur before berries can develop. Because of their size and berry-like shape, flower clusters can be

Table 14.1.

CULTURAL INFORMATION FOR SELECTED TABLE GRAPE CULTIVARS

Cultivar	Type of pruning	Typical no. of spurs or canes per vine	Typical no. of buds retained at pruning on each cane or spur	Requires shoot thinning	Climate zone(s)*	Average ripening period	Color	Comments†
Autumn Royal	spur	12–16	2	yes	3, 4	early Sep	purple-black	very large clusters; seedless
Autumn Seedless	cane or spur	4–6 canes or 12–14 spurs	canes 10–12 (canes mature poorly), 2 spurs	—	4	late Aug to Sep	yellow-green	seedless
Beauty Seedless	spur	12–14	2	yes	3, 4	mid-Jul	black	seedless; E
Black Emerald	cane	4–6	10–14	yes	4	mid-Jul	black	compact clusters; small berries; seedless; E
	spur	12–14	2–6					
Black Monukka	cane	4–6	12–14	no	2, 3, 4	late Aug	purple-black	seedless; E
Black Rose	spur	12–14	2	yes	2, 3, 4	mid- to late Sep	purple to black	very delicate, will break down after rain; E
Blush Seedless	spur	12–14	2	yes	3, 4	late Aug to early Sep	red	seedless; E
Calmeria	cane and spur	2 short canes and 12–14 spurs	2 bud spurs and 12–14 bud canes	no	4	late Sep to early Oct	green to green-amber	poor eating quality
Cardinal	spur	12–14	1	yes	1, 2, 3, 4	late Jul	red	E
Catawba	cane	4–6	12–14	no	2, 3	late Sep	coppery	large, round red berries; aromatic; A/E
Centennial Seedless	spur	12–14	2–3	no	3, 4	late Jul	white	seedless; E
Christmas Rose	spur	12–14	2–3	no	3, 4	mid-Sep	red	crisp
Concord	cane	4–6	12–14	no	1, 2, 3, 4	Sep	green to blue-black	uneven ripening, some green fruit; A/E
	spur	12–14	4–6					
Dawn Seedless	spur	12–14	2–3	yes	3, 4	late Jul	white	seedless; E
Delight	spur	12–14	2	yes	1, 2, 3, 4	mid-Jul	white	seedless
Emperor	spur	12 (24 on old vines)	2–3 (3 bud spurs on older, less productive vines)	—	4	late Sep to Oct	red-purple	E
Exotic	spur	12–14	2	yes	2, 3, 4	late Aug	black	E
Fiesta	cane	4–6	10–14	no	4	early Aug	white	seedless, may have hard seed coats; E
Flame Seedless	spur	12–14	2–3	yes	2, 3, 4	late Jul	red	seedless, very crisp berries; E
Golden Muscat	cane	4	10–14	no	1, 2	midseason	yellow-green	vigorous vines; A/E
	spur	12–14	4–6					
Italia	spur	12–14	2	yes	3, 4	late Aug	white	slight muscat flavor, susceptible to flower thrip damage; E

Table 14.1. cont.

CULTURAL INFORMATION FOR SELECTED TABLE GRAPE CULTIVARS

Cultivar	Type of pruning	Typical no. of spurs or canes per vine	Typical no. of buds retained at pruning on each cane or spur	Requires shoot thinning	Climate zone(s)*	Average ripening period	Color	Comments†
Lady Finger (Olivette Blanche)	cane	4-6	10–14	no	1, 2, 3, 4	late Aug	green-white	large, slender clusters; berries large, elongated; E
Muscat of Alexandria	spur	12–14	2	no	3, 4	mid-Sep	green to golden	strong muscat flavor, may require zinc treatments; E
Niabell	cane	4	10–14	no	2, 3	mid-Jul	blue-black	large berries similar to Concord; excel. on arbors; vigorous, resistant to powdery mildow; A/E
	spur	12–14	4–6					
Niagara	cane	4	10–14	—	1, 2, 3	mid-Aug to Sep	light green	vigorous, good on arbors, resistant to powdery mildew; A/E
Perlette	spur	12–14	2	yes	1, 2, 4	mid-Jul	white	compact clusters require extensive prebloom flower thinning; seedless; E
Pierce	cane	4	10–14	—	1, 2	mid-Aug to Sep	black, slip skin	vigorous, good on arbors, resistant to powdery mildew; A/E
	spur	12–14	4–6			—	—	
Queen	spur	12–14	2	no	3, 4	mid- to late Aug	red-purple	
Red Globe	spur	12–14	2	yes	3, 4	mid-Sep	pink-red	beautiful, large fruit, very appealing
Red Malaga	spur	12–14	2 (may add a cane to increase production)	yes	4	early Aug	red	poor home cultivar; E
Ribier	spur	12–14	1	yes	2, 4	late Aug	black	E
Ruby Seedless	spur	10–14	2	yes	2, 3, 4	mid-Aug	purple	extremely susceptible to powdery mildew and bunch rot; seedless; E
Thompson Seedless	cane	4–6	10–14	no	3, 4	mid-Aug to Sep	white	seedless; E
Tokay	spur	12–18	2 (bilateral or head train)	no	2, 3, 4	late Aug	white to pale pink	will not color well in hot climates, subject to sunburn; E

Notes:

*Climate zones: 1 = South Coast; 2 = Central Coast; 3 = North Coast; 4 = inland valleys and other hot areas.

†Comments: A/E = American or American-European hybrid cultivar; E = European cultivar.

confused with developing berries before they bloom (see figs. 14.1–14.4).

After pollination, the male flower parts fall off (fig. 14.5), and the grape berries begin to grow and develop. Unpollinated flowers fall to the ground during the shatter stage. Pollinated flowers begin to form berries, which continue to grow in size and increase in sugar content until harvest (fig. 14.6). The annual growth cycle of a typical grapevine is shown in figure 14.7. Note that the cycle has many facets, with several events, described above, occurring simultaneously.

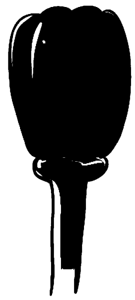


Figure 14.1

The earliest stages of grape flowers entering the bloom period. The calyptra (cap) covering the flower parts is beginning to open.

Figure 14.2

Three flowers, two with the calyptra almost off and one with the calyptra off, exposing the flower parts.

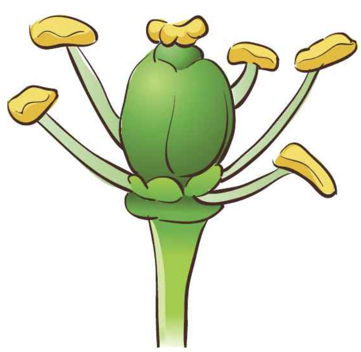


Figure 14.3

A grape flower in bloom after the calyptra has fallen off.

Figure 14.4

A flower cluster in about 85% bloom. Sprays of plant growth regulators (gibberellic acid) are applied commercially when about 50 to 70% of the calyptras have fallen off, producing big, lush grapes, but this is not a common practice in the home garden.

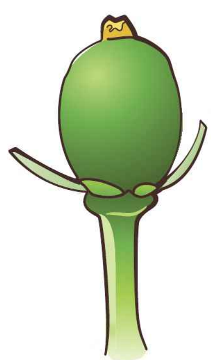


Figure 14.5

A developing young berry. After bloom and pollination, the male flower parts fall off, and the berry begins to develop.

Figure 14.6

A fruit cluster following the shatter stage, when unpollinated flowers have fallen to the ground. Commercial producers begin using growth regulators at this stage, when berries are about 3/16 inch in diameter.

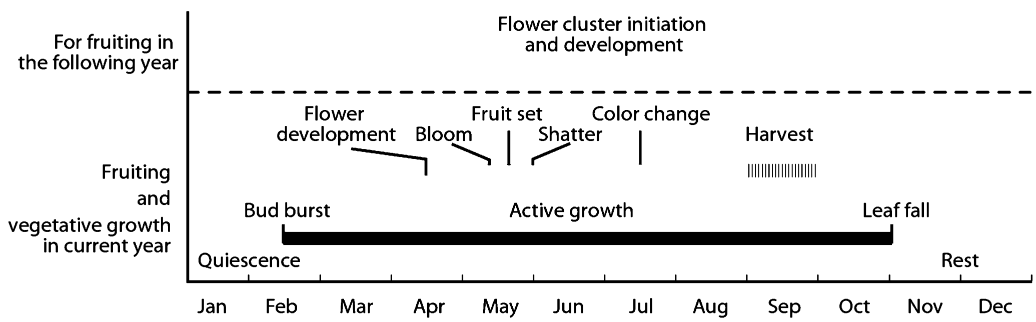


Figure 14.7

Annual growth and fruiting cycle of a grapevine. *Source:* After Shaulis and Pratt 1965.

Planting and Early Care

Planting

Set out plants in January or February. Trim off any broken or damaged roots just above the point of injury. Cut off all canes except the most vigorous one and prune it back to two buds, which is commonly called a spur. Dig the planting hole large enough to accommodate the entire plant. Place the bare-root plant so the two buds left to grow are 4 inches above the soil surface. Irrigate the plants to settle the soil around the roots at planting. Additional irrigation should not be required until 6 to 12 inches of growth has developed in the spring. Protect the new shoots with a sleeve or tube with an open top. A milk carton or plastic jug can serve this function. Fertilize young vines in the early summer, especially in soil with low fertility or if plants are low in vigor.

Let all shoots grow the first season, since shoots and leaves produce a strong root system for future vine development. Protect the young vines from rodents, grasshoppers, and other pests. Insert a 6-foot stake near the plant and train new growth to it by loosely tying it.

Weed Control

Practice clean cultivation the first year or use mulches. Herbicides should not be used until the vine trunk develops mature bark, which usually occurs at the end of the second or third growing season.

Cluster Thinning

To ensure healthy vine development, pinch off all the fruit clusters the first and second years as they appear. In the third and fourth year, pinch off all but one cluster per shoot. Allow full production after the fifth year.

Pruning at the End of the First Growing Season

Grapes can be pruned in the winter after the plants have dropped foliage and are dormant. However, it is usually best to wait until growth just begins in the spring before pruning so that damage to the new

Table 14.2.

CULTURAL INFORMATION FOR SELECTED AMERICAN AND AMERICAN-EUROPEAN HYBRID SEEDLESS TABLE GRAPE CULTIVARS

Cultivar	Ripening season	Color	Flavor	Berry size	Cluster size	Cluster compactness	Vine vigor	Yield per vine	Winter hardiness
Canadice	early	red	good	medium	medium	tight	medium	high	high
Challenger	mid	red	good	large	medium	loose	medium	medium	medium
Glenora	mid	blue	good	medium	medium	compact	medium	low	low
Himrod	early	white	excellent	medium	medium	loose	medium	low	medium
Interlaken	very early	white	good	medium	medium	compact	medium	medium	low
Lakemont	mid	white	good	medium	large	compact	high	high	low
Mars	early	red	good	medium	small	compact	medium	medium	—
Reliance	early	red	good	medium	medium	loose	high	medium	high
Remaily	late mid	white	fair	large	large	compact	medium	high	low
Romulus	late	white	fair	small	large	compact	medium	medium	medium
Suffolk Red	mid	red	good	medium	medium	compact	medium	medium	high
Vanessa	mid	red	good	medium	medium	compact	medium	medium	high
Venus	very early	blue	good	large	large	tight	high	high	medium

Note: Many of these cultivars are not adapted to hot inland climate areas.

Table 14.3.

SELECTED WINE GRAPE CULTIVARS

Cultivar	Type of pruning	Color	Comments
Cabernet Sauvignon	spur	red	best in cool climate; small, dark berries; vigorous vines
Chardonnay	cane	white	small berries, few seed, tough skin; subject to spring frosts in cool areas
Chenin Blanc	spur	white	cool to warm climates; susceptible to bunch rot
French Colombard	spur	white	vigorous vines; good for warmer areas
Gewurztraminer	cane	red-brown	small berries, spicy flavor; picking at proper maturity critical; susceptible to spring frosts
Grenache	spur	light red	good for warm climates
Pinot Chardonnay	spur	white	good for cool climates
Ruby Cabernet	spur	red	very productive; good in warmer areas
White Riesling	spur	white	good for cool areas
Zinfandel	spur	red	cool to warm areas

growth from late spring frosts is avoided. Remove all shoots except the most vigorous one. If first-season growth was relatively weak, prune the shoot back to two buds (a two-bud spur) and replace the vine protection (milk carton, etc.). Place a 6-foot stake for training the vine if you did not do so at planting. Control weeds, gophers, snails, slugs, and so on, as needed. If first-season growth was fairly vigorous, the single shoot can be tied to the stake or trellis without heading it back (fig. 14.8A).

Training the Vine in Its Second Season

If plant growth was weak in the first season and was pruned back to a two-bud spur, select a single vigorous shoot to become the trunk and train it up the stake the second season. The shoot must be tied up every 1 to 2 weeks for adequate support as it grows. Use a vinyl tape that will stretch and not constrict or girdle the shoot. Allow lateral shoots to develop, but remove suckers from the base and lower lateral shoots. If growth was relatively vigorous and a single shoot was selected for training at the start of the second season, it should be trained to the trellis as described below (see fig. 14.8B).

Dormant Pruning at the End of the Second Year

Vines with poor vigor

If the shoot trained up the stake or post has not reached the trellis wire, prune the vine back to two buds and start the training process again, as if it were the start of the second season.

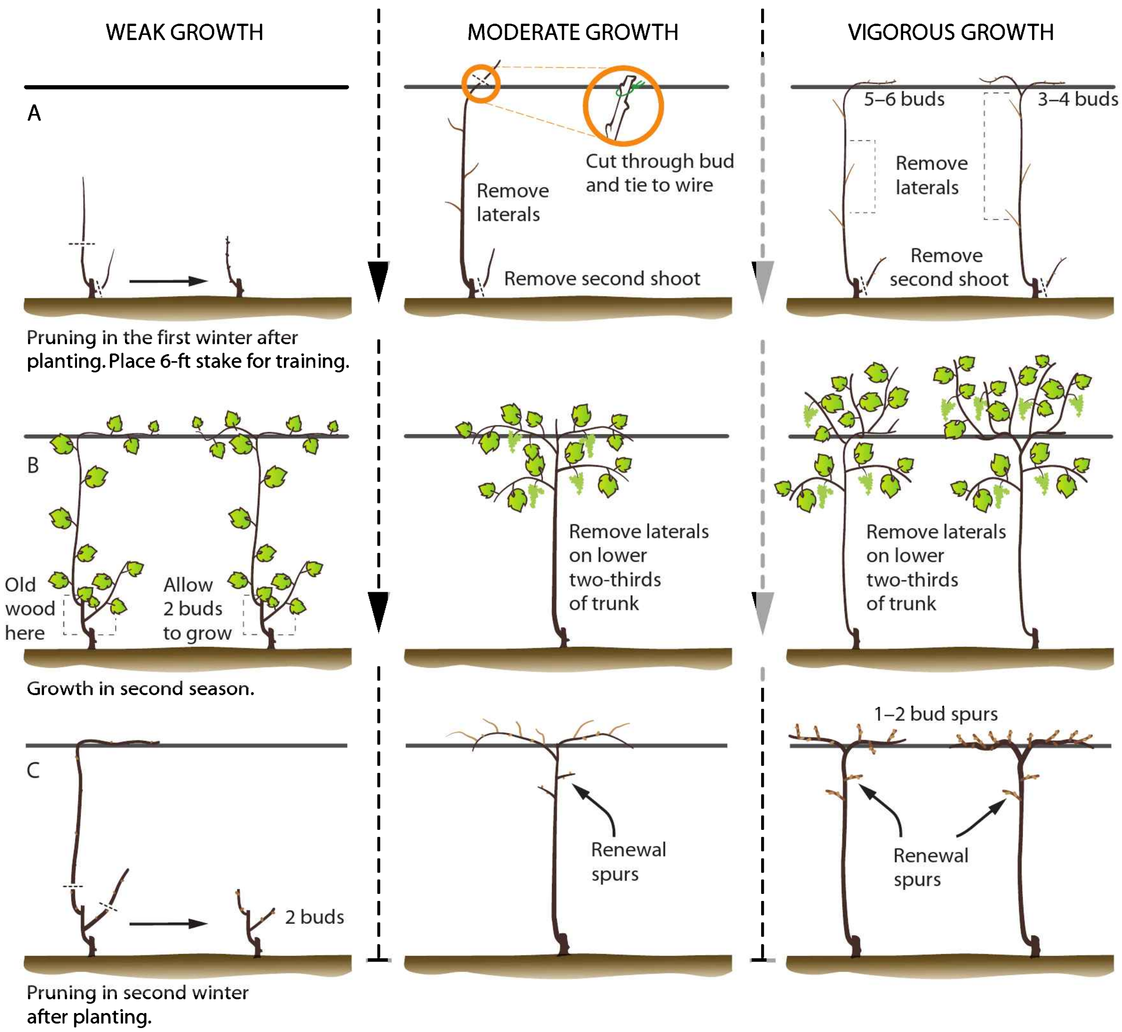


Figure 14.8

Examples of early training of vines with different vigor, using cordon training for spur-pruned grape cultivars. (A) Pruning the first winter after planting. (B) Training the vine in the second season. (C) Dormant pruning at the end of the second year. *Source:* After Jackson and Schuster 1981, pp. 80–81.

Vines with moderate vigor
Shoots with moderate vigor either have made it to the trellis wire without extending out on the wires or have only very weak growth on the wire. Prune the vine back to wood that is at least the diameter of a pencil. If vines are located in a frost-prone area, delay pruning until growth has started. Select and train shoots on the trellis the following spring.

Vigorous vines
Vigorous vines have well-developed trellis shoots and lateral shoots extending from the trellis wire. Thin the lateral shoots until they are 6 to 8 inches apart along the wire. Cut back the shoots to spurs of one or two buds. Shoots that develop from spurs will develop fruit and renewal wood for the following year. Watch for and remove all unwanted suckers and shoots early in the season when they are tender and can be rubbed off easily. In late spring, thin the fruit cluster to one cluster per shoot. Overcropping of young vines can set them back severely (see fig. 14.8C).

Trellising and Training Vines

The type of trellis or support system to be used should be selected and built before second-season growth develops. Training vines to a trellis increases the amount of leaf area with full sun exposure, which leads to increased yields, better fruit quality, and less disease because of better air circulation. Grapevine trellises can be of many configurations. Wine grapes may be trellised at a 40-inch height, which is convenient for harvesting and pruning. A slightly higher trellis (5 ft) is common in table grape production, but arbors or patio structures 7 feet tall or higher may be used. Consider using horizontal crossarms that support canes and foliage for table grapes to spread the fruit and leaf area for better sunlight.

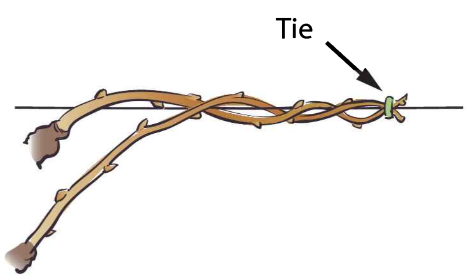
Training systems
There are two general systems for training vines to a trellis. In the head-trained system, a trunk is established and a few to several short main branches (arms, or cordons) are developed that sustain renewal spurs and fruiting canes (see fig. 14.10A). The canes are usually placed on a trellis, arbor, or other support system, but they may simply be supported by one large stake. Cane pruning is typically practiced on head-trained vines in California, although spur pruning is possible if several main branches are developed (see descriptions below). However, the decision to spur-prune or cane-prune will depend on the cultivar, as some cultivars, such as Thompson Seedless, produce few, if any, fruitful shoots from the basal nodes (buds located on the cane closest to the head of the plant). Thus, if Thompson Seedless were to be spur-pruned, the vine would produce fewer fruit clusters.

In the cordon-trained system, a trunk and two or more permanent horizontal arms, or cordons, are established and spur pruning is typically practiced (see fig. 14.10B). The cordons are trained on the trellis and serve as the base for several spurs that produce fruitful shoots each year.

Train shoots on the trellis wire as vigorous second-year vines develop. Vines or cultivars with low vigor may take 1 or 2 additional years to develop. Select the shoots from buds that occur 6 to 12 inches below the trellis wire so that the shoots continue in an upward direction as they approach the wires. Allow the main upright shoot to grow approximately 1 foot above the trellis wire, then cut it back and tie it securely to the trellis. As a result of this procedure, the buds and shoots 1 foot below the trellis are mature enough to support and develop shoots that are trained out onto the trellis (see fig. 14.8C).

Figure 14.9

Tying a cane on a wire. *Source:* After Jackson and Schuster 1981, p. 76.



Tying canes to the trellis wire

Shoots positioned to grow on the trellis wires should be allowed to grow 12 to 18 inches before they are tied down to the wires. Never tie the growing shoot tips to the wire, because they will lose vigor and cease growing (fig. 14.9). Always leave at least 6 inches of shoot tip free beyond the last tie so it can grow in a vertical direction to maintain vigor.

With spur pruning, lateral shoots that form in the axil of leaves on the main shoot or cordon tied on the trellis wire are allowed to grow. Space and thin them during dormant pruning of the vine to form the fruiting spurs.

Figure 14.10

Spur pruning on (A) a head-trained vine and (B) on a cordon-trained vine. *Source:* After Kasimatis et al. 1979.

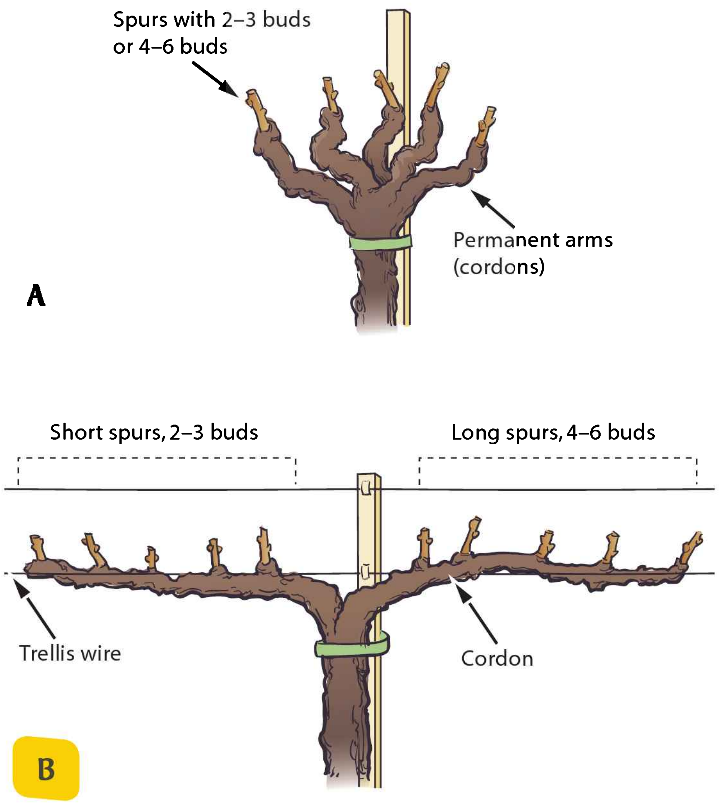
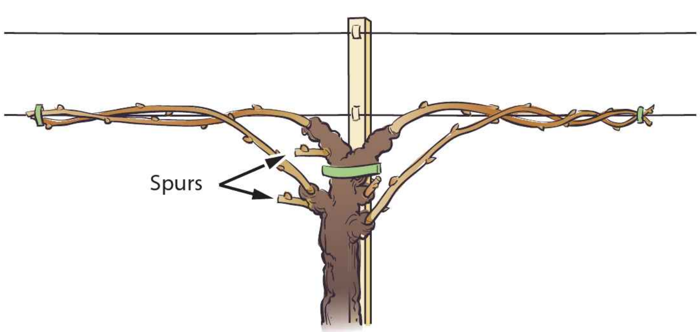


Figure 14.11

Cane pruning on a head-trained vine. *Source:* After Kasimatis et al. 1979.



Pruning Established Vines

Proper pruning modifies the size and form of the vine, rendering it a better producer of high-quality, good-sized fruit. Pruning also aids in balancing vegetative growth and fruit production. Prune grapes while vines are dormant.

Spur pruning

Most grape cultivars are spur-pruned, although many European cultivars may be spur or cane pruned. In spur pruning, the dormant-season shoots that grew the previous summer are selected and spaced along the vine's cordons (main permanent arms) at 6- to 8-inch intervals (fig. 14.10). Select shoots that grew upward in a well-lighted environment for fruitful spurs. Shoots that grew in the shade the previous summer often do not contain fruit buds. Cut each spaced shoot back to several buds and cut all extra shoots completely off the vine. Short spurs (2–3 buds) should be left on fruitful cultivars such as Cardinal, Emperor, Flame, Exotic, Red Globe, Ribier, and Muscat of Alexandria. Long spurs (4–6 buds) are sometimes used for moderately fruitful cultivars such as Concord and Golden Muscat. Keep a total of 20 to 40 buds on mature vines, depending on their vigor. (See the following discussion on matching crop and vine vigor.) The process is continued on an annual basis.

Cane pruning

Thompson Seedless, Black Monukka, Fantasy Seedless, Crimson Seedless, Concord, and most American varieties are usually cane-pruned because the basal buds that

normally produce fruit on spur-pruned cultivars are often not fruitful on these cultivars. Retain well-matured round canes with a diameter from $^3/_8$ to $^5/_8$ inch. Choose canes that develop on top of the vine and were exposed to light during the growing season because their buds are more likely to be fruitful. The canes should have medium node spacing. After selecting the fruiting canes, choose an additional strong cane arising near the base of each fruiting cane and cut it off, leaving a spur with one or two buds. These are renewal spurs, which will produce shoots to be selected as fruiting canes the next year (fig. 14.11). When selecting fruiting canes and renewal spurs, avoid any flattened canes, canes with excessively long internodes, canes of poor maturity, and canes damaged by powdery mildew. Canes that arise from wood older than 1 year (sucker canes) tend to be vigorous and are often rejected; however, they should not be rejected on the basis of origin alone, because they can be as productive as canes that develop from the previous year's wood.

Prune to match the crop to the capacity of each vine. Weaker vines of low vigor should not be expected to carry the same crop load (number of canes) as stronger, more vigorous vines. One way to determine whether a vine is pruned to the correct number of canes is to take an overall view of the cane development and maturity. Vines that develop mature canes of average diameter and internode spacing are the result of pruning to the proper number of canes. Any vine that develops weak canes of small diameter with very close internode spacing should be suspected of being overcropped, and the number of canes should be reduced.

Likewise, vines that produce excessively large-diameter canes with excessively long internodes and poor wood maturity might benefit from the addition of one or more canes. Nitrogen fertilization, irrigation, and soil type are also important in vine vigor and cane development. As a general rule, leave 4 to 6 fruiting canes that have 10 to 14 buds along each cane. Cut the ends off these canes if necessary to attain the desired number of buds.

Producing Quality Wine Grapes

For many years, California winemakers have associated high-quality grapes and wines with low-producing vines that have moderately vigorous shoots. Recent studies by viticulturists at the University of California, Davis, and in the Napa Valley have shown that vigorous vines can produce high-quality grapes and wines if they are trained to permit light to reach the fruit clusters and if enough fruiting spurs and shoots are left at the end of the growing season. Encouraging a larger number of relatively short shoots allows light to reach the fruit. The light also reaches the buds that will be saved to produce grapes the following year. Leaf removal from the base of the shoots and opposite the fruit clusters at flowering also improves lighting conditions and air circulation around the fruit. This process, called leafing, could, however, overexpose the fruit in hot climates, leading to poorer-quality fruit and sunburn. Nonetheless, the leaves that are removed often contain most of the overwintering leafhoppers. This pest can be controlled by raking the leaves away from the vine row; they are in the nymphal stage and will die when exposed to sunlight. The leaves can then be added to the compost pile. The improved air circulation also reduces powdery mildew and bunch rot. Grapes for wine making are usually harvested when their sugar content is about 22% (white wines) or 25% (red wines). Sugar concentration can be estimated with an instrument known as a hand-held refractometer, which is available from dealers selling horticultural or wine-making supplies.

Producing Quality Table Grapes

Many home grape growers are frustrated that their berries do not look as big and lush as the ones in the market. One of the reasons for these results is that most home gardeners fail to thin the fruit clusters enough, girdle the vines, or use any of the commercial techniques such as plant growth regulators. For detailed information on the use of plant growth regulators, thinning techniques, and girdling methods, see *Growing Quality Table Grapes in the Home Garden* (Andris et al. 1991). Table grapes are typically harvested when their sugar content is around 15%.

Irrigation

Irrigation is essential for good vine growth and production. Grapes adapt to low water conditions by reducing fruit production. Applying water deeply and thoroughly by filling the root zone with water is an ideal way to irrigate them. Irrigation frequency depends on the soil type, the rooting depth of the vines, the depth of the soil, and the weather. Flood irrigation every 2 to 3 weeks is usually adequate under good soil conditions and a moderate climate. Grapes may require more frequent irrigations in hot climates and in inland valleys. Drip irrigation is also an excellent method, although the frequency of irrigation must be increased during hot weather.

A fully trellised vine on a warm day in the Central Valley may use about 8 to 10 gallons of water per vine per day. Vines that are less vigorous or untrellised use less water, perhaps 6 to 8 gallons per vine per day. Table 14.4 is a drip irrigation schedule for an average trellised vine. These figures are for the Central Valley and should be used only as a guide; in areas along the coast and in northern parts of the state, the rates will be lower. Requirements in the southern part of the state should be similar to those in the Central Valley. Check the soil profile to be sure that the plants are getting adequate but not too much water.

Timing of irrigations is a critical factor for producing the best-quality grapes. Avoid water stress from the bloom period to berry softening, which occurs when berries give in to finger pressure. Usually, color begins to appear on colored cultivars at the same time. Fruit on the vines may succumb to cracking if the vines are allowed to dry, then wetted again. Maintain an even level of soil moisture to avoid cracking. Also avoid excessive irrigation, which promotes excessive vegetative growth at the expense of fruit quality.

Grape Nutrition

Given good drainage, grapes can adapt well to a wide range of soils and generally have few nutritional needs, with the exception of nitrogen, zinc, and potassium. Applying these nutrients at the right time and in the proper amounts contributes significantly to a successful crop. Table 14.5 is a simple guide to fertilizer management for grapes.

Table 14.4.

DRIP IRRIGATION SCHEDULE FOR GRAPES IN THE CENTRAL VALLEY

	Gallons of water per day per trellised vine under drip irrigation						
Week	Apr	May	Jun	Jul	Aug	Sep	Oct
1	0.5	5.0	8.0	8.0	10.0	6.5	5.0
2	1.0	5.0	8.0	8.0	6.0	6.5	5.0
3	2.0	7.0	8.0	10.0	6.5	5.0	3.0
4	3.5	8.0	8.0	10.0	6.5	5.0	3.0

Overfertilizing with nitrogen can be a problem, whether the nitrogen source is a fertilizer or a leguminous cover crop that fixes nitrogen. Nitrogen fertilizer should be used sparingly on grapes unless a specific deficiency has been diagnosed. Fertilizing with high levels of nitrogen can contribute to excess vegetative growth and may reduce fruit set and fruit quality. Avoid nitrogen fertilization in winter, early spring, or late fall, when the leaves are beginning to change color, as these are periods of lowest nitrogen use and efficiency. Nitrogen fertilizers must be watered in after application.

Phosphorus deficiency is rarely encountered in California soils, except in very alkaline, acidic, shallow, scraped, or depleted soil. Deficiency symptoms may not be noticeable until the vines are seriously deficient. Applying fertilizer that contains both phosphorus and potassium or organic matter such as manure or compost usually supplies adequate amounts to avoid deficiency symptoms.

Zinc, second to nitrogen, is the nutrient found most often deficient in grapes in California. Zinc deficiency is expressed on grapes in several ways. Minor deficiency generally appears as a fading of the green color between the leaf veins. As the degree of deficiency increases, the leaves become less lobed and smaller than normal, and shoots are stunted. Fruit can be affected as well, with clusters often developing small "shot berries" that do not reach nor-

Table 14.5.

GRAPE FERTILIZATION

Element needed	Fertilizer	Amount per vine	When to apply	Comments
nitrogen	ammonium sulfate	½ lb	Berry set stage or following bloom.	Berry set occurs when berries reach ¼ in diameter.
	ammonium nitrate	⅜ lb		
	urea	¼ lb		
	mixed fertilizers	follow label		
	poultry or rabbit manure	5–10 lb	Jan or Feb	Poultry manure may cause zinc deficiency in light, sandy soils.
	steer or cow manure	15–20 lb	Jan or Feb	
zinc	basic or neutral zinc sulfate (52% Zn)	0.6 oz/gal	Apply 1–2 weeks prior to bloom or at full bloom sprayed on foliage.	Apply before bloom to reduce shot berries.
	zinc sulfate (36% Zn)	12 oz/gal	Winter when shoots are dormant; daub on fresh pruning cuts; effective on spur-pruned cultivars only	
		1–2 lb	Apply to soil in shallow trench 18 in from trunk in late fall prior to dormancy	
potassium (applied in a deficiency situation)	potassium sulfate (44% K)	severe deficiency: 5–6 lb	When deficient, apply to soil 6 in deep, 18 in from trunk. Concentrate at vine.	Irrigate after application.
		moderate deficiency: 4 lb		
		mild deficiency: 3 lb		

mal size. To overcome zinc deficiency, daubing a zinc solution onto fresh pruning cuts works well. This must be done during early winter when the vines are dormant and sap is not flowing. A second option is to spray the leaf foliage in the spring 1 to 2 weeks prior to bloom with neutral zinc sulfate (52% zinc) or chelated zinc. Soil applications may also supply the needed zinc. Place the zinc sulfate in a circular trench approximately 6 inches deep and 18 inches from the trunk. Allow the winter rainfall or normal irrigations to move the material into the soil profile. See table 14.5 for details.

Pest Management

Grape pests can be difficult to manage. The key to good pest control is knowing which pests may be a problem and planning accordingly. Some of the most common pests include leafrollers, leaffolders, western grapeleaf skeletonizer, thrips, spider mites, and leafhoppers. Leafhoppers have several generations during the growing season. Beneficial wasps can control leafhoppers if provided with a suitable overwintering site, such as blackberries or prune or plum trees. Planting such plants near your grapes can encourage parasitic wasps, which parasitize the leafhopper eggs and control the pest. Removal of basal leaves and leaves opposite fruit clusters eliminates leafhoppers in the young crawler stage and opens berries to sunlight, which improves color and reduces disease.

Grapeleaf skeletonizer can be severe in some years in some locations; however, the adults are not strong fliers, so they have not spread widely in California. Once the young caterpillars appear, treat the vines with *Bacillus thuringiensis* ssp. *kurstaki*. Provide thorough coverage and treat when the larvae are young. This treatment will also control grape leaffolder and grape leafroller if treatments are applied at the appropriate time.

Spider mites cause grape foliage to turn a strawlike color. In severe cases, the leaves may dry up and the fruit will not mature. Pest mites live on the underside of grape leaves and thrive in dusty conditions. Thorough washing of all leaf surfaces to remove dust, repeated every 10 days, may help remove pest mites off the leaves. Sulfur-tolerant beneficial predaceous mites that feed on the pest mites can also control them. Be sure to purchase the sulfur-tolerant beneficials; otherwise, the sulfur that is used to control powdery mildew will eliminate them. Be aware that many pesticides used to control other grape pests may stimulate mite populations by killing the mites' natural enemies.

The diseases of most concern to home gardeners are powdery mildew and bunch rot. Powdery mildew causes grape berries to shrivel and fail to mature. The canes and fruit become covered with a powdery white fungus. To treat for powdery mildew, dust with sulfur beginning at 4 to 6 inches of shoot growth and repeating every 10 to 14 days thereafter unless temperatures exceed 100°F. Once temperatures drop, resume sulfur applications. Continue applications up to harvest for table grapes. Other fungicides are also registered for powdery mildew control. Treatments with these materials should begin when the shoots are 4 to 6 inches long. Bunch rots generally can be reduced by thinning out four or five basal leaves of the shoots. An application of an appropriate fungicide between bloom and pea-sized berries will also help.

For additional pest control procedures, see table 14.6; also refer to the UCCE publications *Grape Pest Management* (Bettiga 2013) and *Pests of the Garden and Small Farm: A Grower's Guide to Using Less Pesticide* (Flint 1998); also see the UC IPM Grape Pest Management Guidelines website, ipm.ucdavis.edu/PMG/selectnewpest.grapes.html.

Table 14.6.

DIAGNOSIS OF COMMON GRAPE PESTS

Pest	Symptoms	Treatments and comments
grape leafhopper	Stippling on upper leaf surface. May see cast skins of insects and varnish-like spots.	Not usually a serious problem in home gardens. Encourage parasitic wasps to control leafhopper eggs. Remove basal leaves near fruit clusters.
spider mites or grape erineum mites	Tiny yellowish stippling, mostly spreading along the midvein. Fine webbing may be observed. Erineum mite infestations cause the lower leaf surface to develop areas densely lined with a felty mass of plant hairs and some leaf puckering.	Wash leaf surfaces every 7 to 10 days with strong stream of water. Introduce sulfur-tolerant predaceous mites.
European fruit lecanium or grape scale	Small lumps or bumps on stems. Honeydew may be present with lecanium scale.	Spray with dormant oil sprays and control ants.
grape phylloxera	Yellowing of foliage and stunted, slow growth. Roots may be dead or dying. With a hand lens, one may observe small yellowish insects on roots in summer.	No control once infested. Resistant rootstock and good cultural practices may help.
powdery mildew	White, powdery, weblike growth on young plant tissue. Berries may become cracked or scarred.	The most common disease of grapes; many treatment options. See Gubler and Koike 2012 for details.
bunch rots	Rotting and shriveled grapes in late summer.	Thin berry clusters early and remove leaves around berry clusters to improve air circulation; harvest as early as possible. Remove leaf litter, prunings, and fruit mummies in winter.
birds	Colored berries pecked and eaten.	Bag the individual clusters with a paper lunch sack by cutting the bottom out and placing the bag upside-down over the cluster. Leave the bottom open to avoid bunch rots. Wrap the vine or clusters with bird netting. Tie strips of brightly colored surveyor flagging tape or aluminum foil strips in the cluster area.

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UC IPM Grape pest management guidelines. Updated regularly. UC IPM website, http://www.ipm.ucdavis.edu/PMG/selectnewpest.grapes.html.

UC IPM Pest Notes. Updated regularly. UC IPM website, http://www.ipm.ucdavis.edu/homegarden.

Berries 15

Paul M. Vossen, Mark Bolda, and
Donald J. Merhaut

Learning Objectives

Understand the basic cultural practices for growing blackberries, raspberries, blueberries, strawberries, currants, and gooseberries in the home garden in California.

Learn about which cultivars of berries are best suited to various climates in California.

Become acquainted with some of the major pests of berries in the home garden and learn basic information about how to control them.

Berries

Blackberries

Of all the berries, blackberries (in the genus *Rubus,* ssp. *eubatus*) are perhaps the most adapted to California, primarily because of their heat tolerance. The Boysen blackberry does well in the San Joaquin and Sacramento Valleys of California, but most of the commercial production is in the coastal counties.

Cultivars

The three basic types of blackberries are erect, semierect, and trailing. Erect blackberries have stiff, arching canes that can be self-supporting; semierect cultivars produce canes that are stiff but longer than erect blackberries, and trailing cultivars have much longer canes that are not self-supporting. Blackberry plant crowns and root systems live for many years. New canes are produced each year primarily from the crown in trailing cultivars and from crowns and roots in erect and semierect cultivars. Plantings of erect types tend to form hedgerows over time. In all blackberry types, the canes grow vegetatively (primocanes) the first growing season, produce flowers and fruit (floricanes) in the second growing season, then dry out and die. Berries are borne on short lateral shoots produced on the floricanes (fig. 15.1). The following are important blackberry cultivars in California:

Figure 15.1

Trailing blackberry (Logan, left) and upright blackberry (Chester, right). These rows are 8 feet apart, which is closer than the recommended spacing of 9 to 10 feet. *Photo:* P. M. Vossen

Erect and semierect blackberries

- Apache. Midseason; berries large, with good flavor; thornless; fruit can be seedy, tends to have some drupelets turn white in hot, dry weather.
- Black Satin. Midseason; large, shiny black fruit, tart flavor; thornless, hardy, vigorous, semierect; good for processing.
- Cherokee. Midseason; berries medium large, black, firm; vigorous, erect, thorny; tolerates heat.
- Cheyenne. Early; berries very large, firm, attractive; vigorous, erect, moderately thorny, hardy; tolerates heat.
- Chester Thornless. Late; berries large, round, deep black, tart flavor; very vigorous, semierect, productive; good processing berry (fig. 15.2).

Figure 15.2

Chester Thornless blackberries. *Photo:* P. M. Vossen

- Darrow. Vigorous, erect, hardy, productive.
- Hull Thornless. Midseason to late; berries large, soft, sweet flavor; thornless, vigorous, erect, productive.
- Kiowa. Early; large fruited; very thorny, large, erect canes; very productive.
- Navaho. Midseason; thornless, erect, good production.
- Ouchita. Early; medium sized; moderate bearing; thornless, erect.
- Shawnee. Midseason; long fruiting season; berries very large, shiny black, medium firm; vigorous, erect, thorny; very productive, tolerates heat.
- Triple Crown. Late; big, semierect plant; large yields; enormous berries tend to be soft because of uneven ripening; excellent flavor.

Trailing blackberries

- Boysen. Midseason; berries very large, deep maroon, soft, excellent, distinct flavor; thorny but thornless types available; tolerates heat; hybrid of trailing blackberry and raspberry.
- Kotata. Midseason; berries large, glossy black, firm, good flavor; thorny, vigorous, productive.
- Logan. Early; berries medium, long, dark red, soft, excellent, unique flavor; thornless type available; hybrid of trailing blackberry and raspberry.
- Marion. Midseason; berries large, bright black, firm, excellent flavor; thorny, productive.
- Ollalieberry. Early; berries medium to large, bright black, firm, good flavor; vigorous, productive.
- Silvan. Early to midseason; berries large, black, medium firm, excellent flavor; thorny, very productive.
- Thornless Evergreen. Late; berries medium, dark black, firm, mild flavor; very productive, suckers from roots, may be thorny.
- Waldo. Midseason; berries medium, glossy black, firm, mild flavor; thornless, productive.
- Young. Midseason; berries very large, maroon, sweet, excellent flavor.

Obtaining Plants

It is best to purchase certified disease-free plants from a nursery. Although propagating your own berry plants is very easy to do by tip layering stems or by dividing crowns, plants derived from your own or a neighbor's canes could introduce unwanted root disease organisms or viruses into your garden and result in less-vigorous, low-yielding blackberry plants.

Soil Requirements

Although blackberries do well in a variety of soil types, including clay, like many other crops they perform the best in very deep, well-drained, sandy or loamy soil with a slightly acidic pH of 5.5 to 6.5. A good supply of organic matter in the soil improves aeration and drainage and increases water-holding capacity. You may apply organic matter during the summer or fall before you plant. Incorporate about 1 pound per square foot of fully decomposed organic matter such as compost into the soil before making raised beds. Raw organic matter sources such as

manure, straw, or peat moss can also be used but should be allowed to decompose in the soil for several weeks to 2 months prior to planting. Do not incorporate raw, high-carbon forms of organic matter such as sawdust, wood chips, or rice hulls. These materials should be used only as surface mulches to avoid tying up nitrogen during their decomposition.

Figure 15.3

Approximate dimensions of cane and bush berry raised beds.

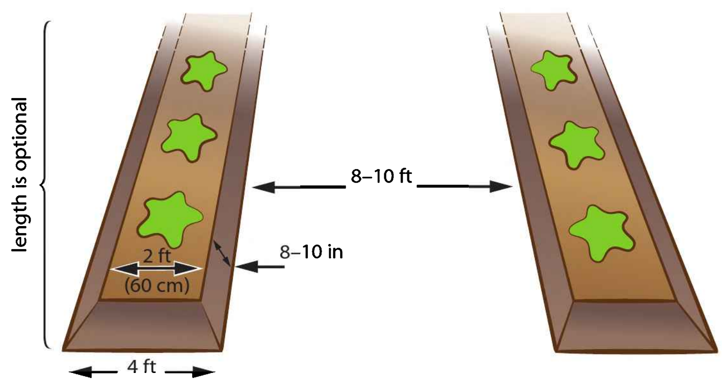
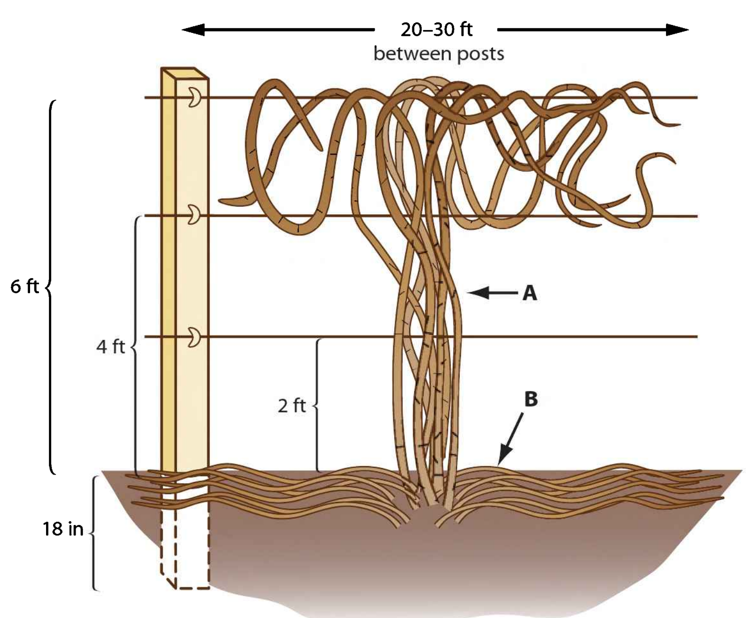


Figure 15.4

Three-wire trellis for trailing blackberries during the growing season (leaves not shown). (A) Canes that have just borne fruit and will die. (B) New growth that will bear fruit the following year. *Source:* After Strik 1993, p. 5.



Raised Beds

Raised beds improve the drainage and growth of blackberries considerably by decreasing the negative effects of heavy soil, winter rains, and excessive summer irrigation. Construct raised beds by adding a soil mix into the native soil or by shoveling soil from the aisles (the area between the rows) to form beds 1 to 2 feet wide at the top that widen to 2 to 4 feet at the base. Beds are generally 8 to 10 inches tall and can be as long as you desire (figure 15.3).

Planting Requirements

Plant bare-root plants in the fall, winter, or as early as you can work the soil in the spring. Dig a shallow hole just large enough to accommodate the roots, prune off any damaged root parts, spread the root mass, and set the plant at about the same depth it was in the nursery. Cover the roots with soil, and water the plants to remove air pockets and settle the soil. Cut the canes on newly set plants to 6 inches at planting time. Potted green plants can be planted any time they are available from the nursery. For best sun exposure, plant rows in a north-south direction, if possible.

Spacing

Space all cultivars 2 to 4 feet apart in the row, leaving 8 to 10 feet between rows. Blackberries tend to produce few root suckers, but new canes emerge every year from the crown area.

Trellis Systems

Trailing blackberries require a trellis system to support the fruiting canes the second year (fig. 15.4). Erect and to some extent semierect blackberries can grow without support, but trellises will keep the planting neater and make harvest easier. Therefore, it is advisable to trellis all blackberries (fig. 15.5).

Set heavy posts at least 2 feet into the ground at each end of the row. Set lighter posts about 20 to 30 feet apart in the row. After setting, the posts should be about 6 feet tall. A two-wire trellis system is generally adequate, with the top wire near the top of the posts and the bottom wire at approximately 3 to 4 feet. Some gardeners use a three-wire system (see fig. 15.4), spacing the wires at 6, 4, and 2 feet.

With erect and semierect cultivars, an alternative is to use a two-wire T trellis made by running wires on each end of crossarms 2 feet wide placed on top of posts that are 3 to 5 feet tall, similar to the system depicted in figure 15.6 for raspberries. Canes may be allowed to grow naturally up and trail over the wires, or they can be trained onto the wires.

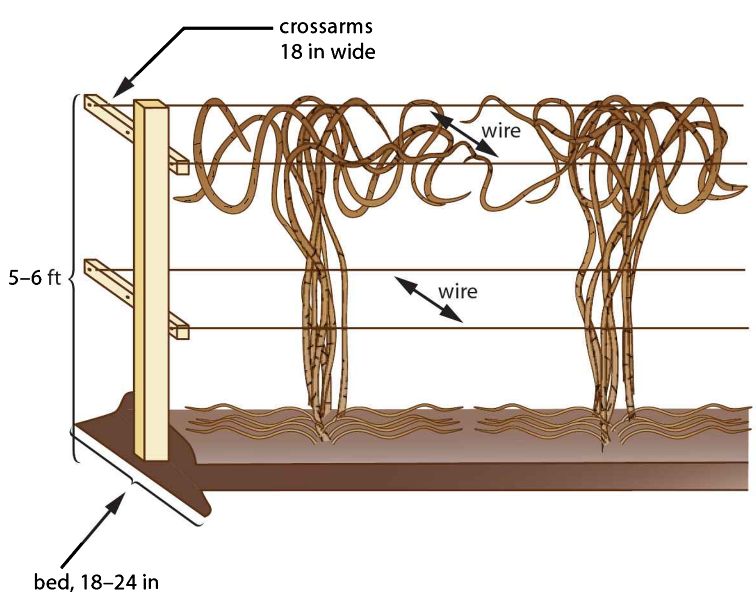
Training canes of trailing and semierect types to an existing fence is an option for home gardens, but training and management may be more difficult with this system.

Figure 15.5

Three-wire trellis used for all types of blackberries (foreground) has not been planted yet. Background shows a row of canes from an erect cultivar. *Photo:* P. M. Vossen

Figure 15.6

Four-wire trellis for raspberries. Upper crossarm is optional and may be replaced with a single wire attached to the posts.



Fertilization

If you use manure, compost, or another source of organic fertilizer, apply it in the late fall or early winter. Apply approximately 50 pounds of an organic-type fertilizer per 100 feet of row. Inorganic fertilizers should be spread over the surface of the soil in the row in early spring just when growth is starting. Apply 5 to 6 pounds of 20-20-20 fertilizer per 100 feet of row. If plants lack vigor, apply an additional 1 pound of ammonium nitrate or similar analysis fertilizer per 100 feet of row at bloom or midsummer, just prior to an irrigation.

Irrigation

Blackberry plants require approximately 1 to 2 inches of water per week from mid-May through October. In all locations, blackberries require frequent irrigations so the soil remains moist at all times but is not saturated, which can rot the roots. Generally, irrigate twice a week; however, during the fruiting stage or during windy, hot conditions, apply water more frequently. When using drip irrigation, water blackberries every day in hot weather or when fruit is ripening.

Pruning and Training

Little pruning is required for any type of blackberry during the establishment year. In subsequent years, pruning and training vary somewhat among the different blackberry types.

Erect cultivars

Erect types produce stiff, upright new canes from the crown and root system that arch over after they grow about 5 to 6 feet long. These cultivars need summer pruning to maximize fruit production. During the summer when these primocanes are approximately 3 to 4 feet tall, pinch off the top 1 to 2 inches. These canes will branch and produce fruit the next year. Train the branched shoots to the trellis wires or allow them to grow up and over the wires. Alternatively, the primocanes can be left unheaded and trained by wrapping them around the wires for fruiting next year, though this practice may result in lower yields. In December to February, remove the floricanes, since they will eventually die or are dead anyway. Let the canes dry down before pruning, since the reserves of carbohydrates descend to the crown as the canes die back. To obtain larger fruit, thin primocanes to three or four of the strongest canes per plant. In late winter, shorten the branched stems to about 2 feet long. If you are growing the planting as a hedgerow, remove any primocanes that grow outside of the desired hedgerow area as they emerge.

Trailing and semierect cultivars

After the first year of establishment, train the primocanes of trailing blackberries onto the trellis system in mid to late winter. In the spring, trailing cultivars produce primocanes that grow along the ground. Keep these trained in a narrow row beneath the bearing canes to prevent injury. Sometime after harvest or during the winter, remove the floricanes. Thin the primocanes, leaving 6 to 12 of the sturdiest canes on each plant to bear next season. Wrap the primocanes around the trellis right after removal of the floricanes. Wrap one or two canes at a time in a spiral around the wires of the trellis, working each way from the plant (see fig. 15.4). Top the primocanes of trailing berries if they grow beyond 10 feet.

Semierect cultivars perform best with summer pruning by pinching off the top 2 inches of primocanes once they are about 5 feet tall to encourage branching. Train the branched canes to trellis wires, or if using a T-trellis described above, allow the branched canes to grow up and over the wires. As with trailing types, primocanes of semierect blackberries do not need winter pruning unless they are too long to manage easily on the trellis.

Pests

For current, detailed information on blackberry pests, see the UC IPM Pest Management Guidelines: Caneberries, ipm.ucdavis.edu/PMG/selectnewpest.caneberry.html, and *Pests of the Garden and Small Farm* (Flint 1998).

Weeds

Blackberries require a weed-free site to perform well. Before developing the site, control all perennial weeds with herbicides or diligent cultivation. Once the plants are in the ground, the best method of weed control is a heavy mulch. Apply mulch materials, such as bark chips, sawdust, peat moss, shredded bark, etc., to a depth of approximately 3 to 4 inches extending 2 feet on each side of the row. Maintain the mulch throughout the life of the planting. If cultivation is necessary, do not dig very deeply because blackberry roots grow very near the surface of the soil.

Insect and mite pests

Redberry mite. Redberry mite is an extremely small mite that causes blackberries to ripen unevenly (some drupelets on the fruit do not ripen and remain red). Horticultural oil products labeled for use on caneberries or blackberries can be

effective in controlling this pest. Apply it starting in the spring when leaf buds are ½ to 1 inch long. Repeat this two or three more times at intervals of 10 days to 21 days. Test the oil mixture on a small part of the planting first to be sure that no plant damage occurs. For further information on managing this pest, see the UC IPM Pest Management Guidelines for caneberries.

Spider mites. Spider mites cause stippling on blackberry leaves, which initially lightens the overall leaf; if left to continue, the infested leaves dry out and die. Plant vigor and fruit production are noticeably reduced, especially when spider mites have infested the plant early in the season. To prevent mite buildup, maintain plant vigor by reducing dust in the planting area and never allowing plants to become drought stressed. Control may be achieved by applying a registered miticide or insecticidal soap.

Raspberry horntail. The larva of this wasp is an S-shaped segmented worm (the larval stage), up to 1 inch long, with a white body and a dark brown head. It has three pairs of legs near the head end and short spines on the tail end. Horntail feeding causes tips of young shoots to wilt during the spring. Cutting open the affected portion of the cane reveals the worm and its tunnel containing brownish granular frass. To control, remove and destroy infested canes. If the insect continues to be a problem, apply a registered insecticide immediately after bloom.

Crown borers. The worms (larval stage) are up to 1 inch long, with a whitish body and a brown head. Attacked plants lack vigor, portions become stunted and weakened, lateral growth wilts in spring, and the entire cane may die. Cutting open lower canes or the crown area reveals larval tunneling through plant tissue. To control borers, keep plants irrigated properly and growing vigorously, since they are attracted to stressed plants. Prune out and destroy infested shoots and canes.

Diseases

Verticillium wilt. This fungus survives and builds up in the soil on other host plants and is then transmitted to blackberry canes. It primarily affects floricanes, rarely primocanes. Floricane leaves turn yellow, wither, and fall, beginning at the base of the cane and progressing upward. Canes take on a bluish black cast and die during the summer as fruit are maturing. Small groups of plants may be affected. There is no cure for Verticillium wilt. Remove and destroy infected plants; avoid planting blackberries in soil formerly planted with other hosts of the fungus, which include cucurbits, potato, tomato, eggplant, peppers, spinach, stone fruits, sunflower, and many other crops. Plant resistant cultivars such as Logan, Chehalem, and Ollalie.

Armillaria root rot. This fungus survives in the soil for many years and is especially prevalent in soil previously planted to apples. The entire blackberry plant becomes weakened and can be killed quite rapidly once the first symptoms appear. White fungal growth between the bark and wood near the ground level is evidence of the fungus. There is no cure for Armillaria root rot. Remove diseased plants as soon as possible; do not replant berries in the affected area for at least 2 years.

Phytophthora root rot. The fungus infects weakened roots as a result of excess soil moisture. In the spring, plants fail to leaf out fully; small leaves turn yellow, and the entire plant dies. Interior wood on canes in the root-crown area turns brown and rots. To control, plant berries on raised beds in deep, well-drained soil. Do not stress plants for water, but be careful not to overwater plants in the summer.

Cane and leaf spot. This fungus survives on infected canes and leaves. Spores are dispersed by splashing water. Infection appears as small red-bordered spots with whitish centers on leaves and canes. Plants have reduced vigor and may lose some leaves prematurely, leading to sun-

burn of canes. To control, avoid overhead irrigation. After harvest and before fall rains, prune out and destroy old wood and apply fixed copper fungicides labeled for use on berries. A second application in January may be necessary in rainy locations (fig. 15.7)

Yellow rust. The fungus overwinters on fruiting canes. Spores released from infected canes are spread by wind during spring and summer. Small, yellow, blister-like pustules appear in the spring, first on fruiting canes then on new leaves. Canes dry out and crack, preventing proper ripening of fruit. To control, avoid overhead irrigation. Prune out and destroy diseased canes before fall rains. Apply a fixed copper fungicide in spring when new laterals are leafing out and again when flowers begin to open.

Orange rust. This fungus is the only systemic rust in caneberries. Bright orange, blister-like pustules cover the underside of leaves in spring. Spores are released from the pustules in May and are then spread by wind. Diseased shoots seem to recover by midsummer, but developing canes are smaller than normal and bear no fruit the following year. No fungicides are effective against this fungus. Remove entire affected blackberry plants, including the roots, and destroy them.

Figure 15.7

Cane and leaf spot fungus on blackberry canes and leaves. *Photo:* P. M. Vossen

Crown gall. A bacterium that survives in the soil and is spread by splashing water, pruning, and cultivation tools. Wart-like growths appear on the roots and crown area of canes. Severely affected plants become stunted. To control, cut out infected canes during hot, dry weather, and disinfect pruning tools before using on healthy plants. Do not purchase any plants that show evidence of crown gall symptoms.

Dwarf virus. This virus is transmitted by aphids after feeding on infected plants. Symptoms include weak, spindly canes and leaves that cup downward and redden prematurely in fall. Plants become unproductive in 2 to 3 years, and berries crumble. There is no cure for dwarf virus. Remove infected plants immediately. Obtain virus-free plants from a nursery and replant.

Dieback. A physiological disorder in which canes and laterals leaf out after a delay, then wilt and die back at the tips in early spring as the first leaves are unfolding. This disorder is specific to certain cultivars and may be associated with freezing injury, winter drought, or insufficient chilling. To control, maintain late-fall and winter irrigations so that plants do not become drought stressed. In some cases, the cultivar just may be unadapted for the area where it is being grown, and you may have to switch to another cultivar.

Raspberries

Raspberries *(Rubus idaeus, R. neglectus, R. occidentalis)* are best adapted to the cool coastal climates of California, with one exception: the Bababerry cultivar seems to tolerate the heat of the southern and central valleys. Most raspberry cultivars do not tolerate heavy soil and generally require deep, well-drained soil and ade-

Figure 15.8

Yellow and red raspberries. *Photo:* P. M. Vossen

quate summer irrigation to produce consistent crops. Raspberry cultivars can be divided into four groups, based on their fruit color: red, golden yellow, black, and purple, with red cultivars by far being the most common (fig. 15.8). Other than color, raspberry fruit differ from blackberry fruit in that the raspberry receptacle stays on the plant when picked and the drupelets form a thimble-shaped fruit, whereas the blackberry receptacle stays with the fruit when picked.

Cultivars

Red raspberries *(Rubus idaeus)* can be divided into two types. Summer-bearing, or floricane, cultivars are the most common; they produce biennial primocanes that grow one year and develop into floricanes the next year. Fall-bearing, or primocane, cultivars produce canes that bear fruit on the top portion of the current season's growth in late summer and fall. If these canes are left to overwinter, they bear fruit in the spring on the lower portions that did not fruit the previous fall. The characteristics of several important raspberry cultivars are given below.

Red raspberries, summer bearing

- Canby. Berries medium to large, bright red, firm; susceptible to root rot.
- Chilcotin. Berries large, bright red, fairly firm, harvested over a long season; very productive, susceptible to root rot.
- Chilliwack. Berries large, bright red, firm, resistant to fruit rot, excellent flavor; vigorous, spine-free, hardy, some root rot resistance.
- Comox. Berries large, medium red, firm, resistant to fruit rot, fair flavor; productive but highly susceptible to root rot.
- Haida. Berries medium sized, medium red, firm, good flavor; some root rot resistance.
- Meeker. Berries medium to large, medium to dark red, firm, good flavor.
- Newburgh. Berries large, light red, medium firm, resistant to root rot.
- Nootka. Berries medium sized, medium red, firm; very productive, susceptible to root rot.
- Nova. Berries medium sized, good tasting, good quality; the standard floricane-bearing cultivar for commercial growers in California for many years; production begins in May or June, and if new canes are tipped in July, they can be made to bear a small fall crop as well.
- Prelude. Berries medium sized; can bear in April if properly chilled, but chilling in coastal California is not sufficient for this cultivar to flower and fruit properly.
- Skeena. Berries medium to large, bright red, firm, good flavor, long harvest season; highly susceptible to root rot; nearly spine-free.
- Sumner. Berries medium sized, medium red, firm, sweet, excellent flavor; most tolerant cultivar for heavy, poorly drained soil.
- Tulameen. Berries very large, firm, late, good flavor; high yielding.
- Willamette. Berries large, dark red, fairly firm, mild flavor; susceptible to root rot; primocanes produce a late-fall crop.

Red raspberries, fall bearing

Amity. Berries medium sized, medium dark red, very firm, good flavor; susceptible to root rot, almost spine-free.

August Red. Early maturing; berries medium sized, bright red, soft, good flavor; self-supporting plants.

Autumn Bliss. Early ripening; berries very large, excellent flavor; fruit can be a bit soft in warm weather.

Bababerry. Berries very large, red, soft; good producer, tolerates summer heat.

Caroline. Berries very good tasting and good sized; bears from June to July; canes are quite abundant, and a hedgerow of this cultivar is very full and not tall.

Fall Red. Berries small, red, fairly firm, good flavor; vigorous and productive but require support.

Heritage. Berries medium red, very firm, attractive, mild flavor; large fall crop ripens in August; standard fall-bearing cultivar of red raspberries in California for decades.

Himbo Top. Berries have good flavor; production is fair; tall caned, late bearing; early fruit can be off-color.

Indian Summer. Berries red, very aromatic, crumble frequently, good flavor; productive and vigorous.

Joan J. Berries very large, productive; uneven ripening of fruit makes quality a problem.

Josephine. Berries large, with good flavor; relatively low yields. Good midseason cultivar.

Polka. Berries good flavored, mid to small sized; excellent, productive cultivar, fruits for 2 months in mid to late season.

Redwing. Berries medium sized, red, firm, good flavor; ripens 2 weeks earlier than Heritage.

September. Berries medium sized, bright red, firm, attractive, good quality.

Summit. Berries similar to Heritage but slightly darker; matures about 10 days earlier than Heritage.

Golden yellow raspberries *(Rubus idaeus)*

These raspberries are mutants of red raspberries that do not express the pigment for red color.

Anne. Berries medium sized, conical, excellent flavor, very soft when ripe, color holds; good production in late July through August; the best golden-fruited raspberry.

Fall Gold. Berries yellow, moderately firm, very good flavor; moderate to poor production; often virus-infested; ripens 10 days before Heritage.

Golden Harvest. Berries similar to Heritage in size, season, and sweetness.

Honey Queen. Berries medium sized, sweet; good yielding; summer bearing.

Black raspberries *(Rubus occidentalis)* (Black caps)

Black cap raspberries produce fruit on arched or trailing canes. New canes are not produced from old roots; instead, they develop from the base of old canes. Note that black raspberries do not produce heavily and generally do not have the same level of production as a red raspberry or blackberry.

Bristol. Berries medium sized, firm, good flavor.

Cumberland. Berries small, firm, good flavor.

Jewel. Berries have a strong flavor, good for marmalades and jams; vigorous, decent bearing, midseason.

Mac Black. Berries good sized, mid to late season.

Munger. Berries small, blue-black, firm, good flavor, ripen in July; intolerant of wet soil.

Purple raspberries *(Rubus neglectus)*

Purple raspberries are hybrids of red and black raspberries. Their growth habit is similar to that of blackberries. The berries are excellent for pies because of their distinctive flavor. Purple raspberries do not produce heavily, and their yields are typically much less than a red raspberry.

Amethyst. Berries large, oval, firm, pur-

ple, shiny skin; summer bearing; no root suckers; very productive; excellent for desserts.

Brandywine. Berries large, round, reddish purple, very tart flavor; plant habit similar to black caps but more vigorous; summer bearing; no root suckers formed; one of the best cultivars for pies or processing.

Royalty. Berries very large, soft, and sweet when fully ripe; summer bearing, highly productive; suckers produced from roots like red raspberries.

Propagation

Most raspberries develop a proliferation of shoot suckers from the root system that can be broken off easily to propagate plants. Propagation by layering primocanes is also possible. It is best, however, to purchase certified disease-free raspberry plants from a nursery. Plants from one's own planting or from a neighbor's yard could introduce root disease organisms or accumulated viruses into the garden.

Soil Requirements

Raspberries grow best when the soil pH is between 5.5 and 6.5. A good supply of organic matter in the soil improves aeration and drainage and increases water-holding capacity. Incorporate about 1 pound per square foot of fully decomposed organic matter such as compost into the soil before making raised beds. Raw organic matter sources such as manure, straw, or peat moss can also be used but should be allowed to decompose in the soil for several weeks to 2 months prior to planting. Do not incorporate raw, high-carbon forms of organic matter such as sawdust, wood chips, or rice hulls. These materials should be used only as surface mulches to avoid tying up nitrogen during their decomposition. All raspberries should be grown on raised beds, which can be prepared by adding a prepared soil mix into the native soil or by shoveling soil from between rows into a berm and flattening it off to whatever length desired. These berms should be approximately 1 to 2 feet wide and 8 to 10 inches high. Raised beds help prevent problems caused by poor drainage associated with heavy winter rains, heavy soil, or too much summer irrigation (see fig. 15.3).

Planting Requirements and Systems

Plant raspberries at the proper depth. The primary roots of red raspberries, which grow mainly in a horizontal direction, give rise to the shoots of primocanes. If the primary roots are planted much deeper than 2 inches, the roots frequently do not have enough energy to push shoots up through the ground.

Plant raspberries from late fall through early spring. Dig a shallow hole large enough to accommodate the roots. Prune off any damaged root parts. Spread the root mass and set the plant so that the highest point of root attachment to the cane is 1 to 2 inches below ground level. Cover the roots with soil and press firmly to remove air pockets. Water the plants to settle the soil. Cut the canes on newly set plants to 6 inches long.

If a hedgerow system is desired, space red raspberry plants 1 to 2 feet apart in the row with 8 to 10 feet between rows. If possible, run the rows in a north-south direction to get equal sun exposure on both sides. Allow the primocanes to develop and spread along the row. Prevent them from spreading wider than 12 to 24 inches by removing suckers that develop outside the rows in the aisles.

Being much larger plants than red and yellow raspberries, black and purple raspberries need more space. Set plants 2 to 4 feet apart in the row, with 8 to 10 feet between rows. Some purple raspberries produce root suckers; these should not be allowed to grow.

In most cases, raspberries need a supporting structure to hold the canes upright. In the hedgerow system, wires are supported along the outside edges of the rows at the ends of crossarms on large

posts placed about 20 feet apart. The posts should be 6 to 7 feet tall. A three- or four-wire system is usually easiest to manage (see fig. 15.6). The two lower wires used in either system are approximately 30 inches above the ground on crossarms about 18 to 24 inches wide at the edge of the row (fig. 15.9). If large posts with crossarms are not used, wires can be supported with smaller wooden or steel posts every 6 to 8 feet down the row. These wires prevent the canes from flopping over into the aisle. In the three-wire system, an additional wire is placed about 5 to 6 feet above the ground. In the four-wire system, an additional crossarm 18 to 24 inches wide is placed 5 to 6 feet above the ground, with wires attached to each arm.

Figure 15.9

Raspberry trellis, which holds the canes upright. The three crossarms are 18 inches wide and hold six wires. *Photo:* P. M. Vossen

Figure 15.10

Minisprinkler irrigation for raspberries wet the full surface of a long, narrow, raised bed. *Photo:* P. M. Vossen

Fertilization

Apply manures, composts, or other organic fertilizers in the late fall or early winter at a rate of approximately 50 pounds per 100 feet of row. Apply inorganic fertilizers in early spring when new growth starts at a rate of 4 to 6 pounds of 20-20-20 per 100 feet of row. Fall-bearing raspberries require an additional fertilizer application before fruiting. When new canes start to bloom, spread 1 to 2 pounds of ammonium nitrate, or 3 to 6 pounds of blood meal, fish meal, or feather meal, per 100 feet of row.

Irrigation

Raspberries require 1 to 2 inches of water per week from June through September and about half that amount when the weather is cooler in early spring and fall. Extremely warm and windy conditions increase water requirements. Raspberries should be kept moist at all times without saturating the soil, which can encourage the roots to rot. If raspberries are fruiting during warm weather, daily irrigation may be required. Generally, however, irrigations should be applied twice per week. Overhead irrigation is not recommended for raspberries because it promotes fruit rot and leaf rust. The best irrigation systems are minisprinklers or double drip lines that have emitters spaced 6 to 12 inches apart that wet an entire band underneath

the foliage (fig. 15.10). With drip irrigation, raspberries should be watered daily during fruiting or hot weather.

Pruning

Summer-bearing (floricane) red raspberries
Sometime after harvest, remove and destroy all floricanes on which fruit was borne. These canes will die soon and will become havens for diseases and insect pests, and they also interfere with air circulation and continuing cultural practices. Do not tip or pinch the primocanes. In the dormant season, remove all weak, broken, and disease- and insect-damaged canes. In the hill system, leave 10 to 12 of the strongest canes in each hill; in the hedgerow system, narrow the row to 15 to 18 inches wide and thin to about 4 to 10 strong canes per foot of row. In the dormant season, shorten the remaining canes in both planting systems to about 6 feet. Tie the canes to the trellis system if necessary (fig. 15.11).

Figure 15.11

These 5-foot-tall overwintered floricanes are ready to flower and fruit. The shorter primocanes will also grow to 5 feet tall but will flower and fruit much later (the second crop). *Photo:* P. M. Vossen

Fall-bearing (primocane) red raspberries
Fall-bearing raspberries can produce a fall and a summer crop. Cut all canes to ground level when plants are dormant, usually in the winter before growth begins. When the new primocanes emerge in the spring, maintain a row width of 12 to 18 inches by removing suckers that grow outside the row. These canes will produce a crop in the summer and fall on the tips of the primocanes. For a spring or early-summer crop from those same canes, leave them to overwinter; they will fruit the following spring on the lower portion of canes, the portion that did not fruit the previous year. In the dormant season, remove weak or damaged canes and the tips that fruited the previous fall; thin them to 4 to 10 strong canes evenly spaced per foot of row.

Black and purple raspberries
Tip the primocanes by removing 3 to 4 inches of new growth during the late spring or early summer. Top black cap berries to a height of 2 feet and purple berries to 2½ feet. Topping usually must be done two or three times during the summer. Primocanes produce many laterals. During the dormant season, remove all damaged canes and those less than ½ inch in diameter. Lateral branches also should be shortened during the dormant season to approximately 8 to 10 inches for black caps and 12 to 14 inches for purple cultivars. Cut unbranched canes to 2½ to 3 feet. After harvest the following summer, cut all floricanes down to the ground.

Pests

For current, detailed information on raspberry pests, see the UC IPM Pest

Management Guidelines: Caneberries, ipm.ucdavis.edu/PMG/selectnewpest.caneberry.html, and *Pests of the Garden and Small Farm* (Flint 1998).

Weeds

In the year before you plant, eliminate all perennial weeds and do not permit weeds to go to seed. Use very diligent cultivation and herbicides as needed. After planting, the best method for controlling weeds in raspberries is to apply a heavy layer of mulch approximately 2 to 4 inches deep around the plants. Maintain this mulch throughout the life of the planting. Good materials to use include sawdust, shredded bark, bark or wood chips, newspaper, grass clippings, or compost. Raspberries must be maintained completely weed-free to grow and fruit properly.

Insects and mites

Spider mites. Spider mites can be initially detected by yellow stippling on the leaves, followed by the leaves taking on a lighter green color then dying and falling off if the mite infestation is not controlled. To prevent spider mites, maintain plant vigor with good irrigation and nutrition practices and eliminate dust that accumulates around plant leaves, which favors development of mite colonies. For control, apply insecticidal soaps or miticides registered for home use (fig. 15.12).

Figure 15.12

Mites on the upper surface of a raspberry leaf. *Photo:* P. M. Vossen

Raspberry horntail. The larva of this wasp is an S-shaped segmented worm up to 1 inch long, with a white body and a dark brown head. It has three pairs of legs near the head and a short spine on the tail end. Its feeding causes the tips of young shoots to wilt during the spring; canes may die back by summer. Cutting open the affected portion of the cane reveals a thick white worm or a tunnel containing brownish granular material. There is one generation per year; adults emerge through a hole cut in the side of old canes in April or May and lay eggs inside new canes, causing pronounced swelling. To control, remove and destroy infested canes. If this insect has been a problem in past years, apply an insecticide registered to control it immediately after bloom.

Crown borers. The larva of this moth is a worm up to 1 inch long, with a whitish body and a brown head. Affected plants lack vigor; portions become stunted and weakened, lateral growth wilts in the spring, and the entire cane may die later. Cutting open lower canes or the crown area reveals worms tunneling through plant tissue. Raspberry crown borer requires 2 years to complete one generation. Adults emerge from the crown area in late summer and lay eggs on leaves and stems. Larvae penetrate the bark and remain there through winter. Feeding occurs inside canes in the crown area during the next two growing seasons. To control, keep plants properly irrigated and growing vigorously because borers are attracted to stressed plants. Prune out and destroy infested shoots and canes.

Raspberry sawfly. The caterpillar-like larva is up to ⅔ inch long, with a bristly, pale green body and dark brown stripes down the back. Small holes from feeding appear in leaves and increase in size in

May and June until only the veins remain and leaves become skeletonized. Raspberry sawfly has only one generation per year; adults emerge from the soil in April or May and insert eggs in leaf tissue. Larvae feed until June, then drop to the ground and pupate in the soil. The short life cycle and lack of severity of leaf damage all but eliminate the need for control of this pest unless plants become completely defoliated.

Raspberry aphid. Small, green, pear-shaped insect up to 1⁄16 inch long that may have wings. They sometimes cluster on new growth or along the stem. Damage is not serious unless they cover the entire plant. To control, apply a strong spray of water or insecticidal soap mix.

Rose leafhopper. Small, narrow, whitish insect up to 1⁄8 inch long that may be confused with whitefly; closer inspection reveals them to resemble minute grasshoppers. The insects can be found on the underside of leaves and crawl and hop when disturbed. Adults feed on the leaves in spring through fall, creating tiny white spots; numerous spots may coalesce, resulting in bleached-looking foliage. Damage is rarely serious enough to justify treatment.

Figure 15.13

Root rot on raspberry. Note that the lower portion of the cane and the roots are brown and rotten. *Photo:* P. M. Vossen

Diseases

Verticillium wilt. The fungus survives in the soil, building up on other hosts. Leaves turn yellow, wither, and fall, beginning at the base of canes and progressing upward. Fruiting canes may take on a blue-black cast and die during the summer as fruit are maturing. Small groups of plants may be affected. There is no cure for Verticillium wilt. Remove and destroy infected plants. Avoid planting cane fruits in soil formerly planted with other Verticillium hosts. Do not move infected plants to other parts of the garden.

Armillaria root rot. This fungus survives in the soil for many years and is especially prevalent in soil previously planted to apples. The entire raspberry plant becomes weakened and can be killed quite rapidly once the first symptoms appear. White fungal growth between the bark and wood near the ground level is evidence of the fungus. There is no cure for Armillaria root rot. Remove diseased plants as soon as possible; do not replant berries in the affected area for at least 2 years.

Phytophthora root rot. The fungus infects roots weakened by excess soil moisture. Plants in the spring fail to leaf out fully; small leaves turn yellow, and the entire plant dies. To control, plant on raised beds in deep, well-drained soil and do not allow plants to become stressed by uneven watering (fig. 15.13). Do not overwater plants during the growing season.

Cane and leaf spot. Only a minor problem on raspberries.

Crown gall. The bacterium survives in the soil and is spread by splashing water and pruning or cultivating tools. Wart-like growths appear on the roots and the crown area of canes. Severely affected plants may become stunted. To control, cut off and dig out infected canes during hot, dry weather and destroy the plants.

Do not plant plants with crown gall symptoms.

Yellow rust. Yellow rust on raspberries first appears on the tops of the very lowest leaves in May and June, followed by a more noticeable infection on the bottoms of the leaves. Yellow rust will not kill the plant, but it can significantly contaminate harvested fruit with unsightly residues of spores. Yellow rust infections are marked by the presence of black overwintering teleospores in the late fall. Keeping foliage dry and the occasional use of sulfur, oil, or a fixed copper product keep yellow rust in check. Bury or compost fallen leaves and plant residues left after pruning operations to lower disease carryover to the following year.

Viral diseases. Viruses are transmitted mostly by feeding aphids, but a major virus, raspberry bushy dwarf virus, is spread by pollen from bees. Weak, spindly canes develop; leaves cup downward and redden prematurely in fall; plants become unproductive in 2 to 3 years; berries crumble (fig. 15.14). There is no cure for viral diseases. Remove infected plants immediately. Purchase only virus-free plants from the nursery.

Spring dieback. This physiological disorder is associated with delayed leafing out. Canes and laterals wilt and die back at the tips in early spring as first leaves unfold. The cause is not yet determined, but it may be associated with freezing injury, winter drought, or insufficient chilling. To control, maintain adequate irrigation for plants until winter rains take over.

Figure 15.14

Small, crumbling berries caused by virus infection. *Photo:* P. M. Vossen

Blueberries

Blueberries have become very popular in California for commercial and home garden production as well as ornamental purposes. Like many other crops, the blueberry's evergreen growth is much different in California than in other parts of the United States, so cultural requirements for California may be slightly different as well. Blueberries can be grown successfully in many of areas of California if the right cultivars are selected and the planting is managed properly. The cultivar selection will likely expand in the future as other subtropical and Mediterranean regions, such as New Zealand, Australia, and South America, pursue blueberry breeding and production programs.

Blueberry (*Vaccinium* spp.) is a member of the family Ericaceae. This family includes other commonly known ornamentals such as azalea and rhododendron (*Rhododendron* spp.), heath (*Erica* spp.), and mountain laurel (*Kalmia* spp.). There are many California native ericaceous plants, including the madrone tree *(Arbutus menziesii)*, the many species of manzanita (*Arctostaphylos* spp.), huckleberry *(Vaccinium ovatum)*, *Comarostaphylis* spp., and *Ornithostaphylos* spp. What has kept blueberries from being grown in southern California in the past was the high amount of chilling most cultivars needed to break dormancy (> 800 hours). However, during the past 50 years, great accomplishments have been made by breeders in Florida

Figure 15.15

Cluster of ripe blueberry fruit. *Photo:* P. M. Vossen

and Georgia and other southern states to develop blueberry cultivars that require very little chilling.

Vaccinium is the genus of ericaceous plants that comprises all edible commercial ericaceous fruit. This genus is very diverse, both genetically and geographically. The lowbush blueberry *(V. angustifolium)* and cranberry *(V. macrocarpon)* are native to cold temperate climates of the northeastern United States and Canada. However, some less commonly known species, such as *V. pahalae* (ohelo berry) and *V. acrobracteatum*, are native to the volcanic cinder cones of the Hawaiian Islands and New Guinea, respectively. Even though these exotic species are very beautiful and worth studying for their ornamental qualities, they have not been used in any breeding lines for commercial blueberry production.

Types and Cultivars

Lowbush blueberry

Vaccinium angustifolium is the lowbush blueberry that is native to the northeastern United States and Canada. Fruit from native stands of this species has been collected for centuries. However, like the cranberry and ligonberry, this species requires too many hours of chilling to be successfully grown in most parts of California.

Northern highbush blueberry

Vaccinium corymbosum is native to the eastern region of the United States. Many blueberry cultivars currently available have this species in the parentage. However, many cultivars that have this species and the other northern species such as the lowbush blueberry as a major portion of their genetic background usually require many chilling hours (> 800). Because of this, most northern highbush blueberries are well suited to colder areas of northern California but are not suitable in many coastal areas of the state or in most parts of southern California (fig. 15.15).

Early season

- EarliBlue. Berries medium sized, loose clustered, light blue, firm, resistant to cracking, good sweet flavor; vigorous, erect, productive; resistant to powdery mildew but very susceptible to root rot.
- Duke. Berries medium sized, light blue, firm, good flavor; vigorous, erect, open, productive.
- Reka. Berries mild flavored; rapid growing, highly productive.
- Spartan. Berries very large, light blue, firm, excellent flavor; vigorous, erect, open, productive.
- Patriot. Berries very large, slightly flat, medium blue, excellent flavor; vigorous, moderately erect, open, very productive; tolerates heavy, wet soil.
- Collins. Berries large, light blue, firm, excellent flavor; medium sized, slightly spreading, productive.

Midseason

- Blue Ray. Berries very large, light blue, firm, excellent flavor; vigorous, erect, open, productive.

Toro. Berries very large, dark blue, firm, mild flavor; very productive.

Chandler. Berries extremely large, excellent flavor; moderate vigor.

Blue Crop. Berries very large, light blue, firm, good flavor; vigorous, erect, open, very productive (tends to overproduce); one of the main commercial cultivars.

Nelson. Berries very large, excellent flavor; vigorous, high yielding.

Late season

Legacy. Berries medium sized, light blue, good flavor; productive and vigorous, even in southern California.

Berkeley. Berries very large, light blue, firm, mild flavor and mild acidity; vigorous, open, spreading, very productive.

Darrow. Berries medium sized, light blue, firm, excellent flavor; vigorous, erect, consistently productive.

Late Blue. Berries large, firm, good flavor; vigorous, erect, productive.

Elliott. Berries medium sized, mild flavor, tart; vigorous, erect, consistently productive.

Low-chill *Vaccinium* species

Low-chill blueberry production began in Florida in the late 1800s with the collection and cultivation of wild rabbiteye blueberries *(V. ashei)* by M. A. Sapp. Eventually, commercial growers began collecting any wild *V. ashei*, which resulted in the production of poor-quality fruit. The production of substandard fruit resulted in the decline of the rabbiteye industry, especially when the USDA introduced much higher-quality highbush blueberry cultivars in the 1920s. Collection of *V. ashei* was resumed in the 1930s by Jackson M. Batchelor of the USDA. However, development and breeding of both rabbiteye and highbush blueberries discontinued in the 1940s, when most U.S. resources were directed to the efforts of World War II (Sharpe 1954). It was not until 1951 that Ralph Sharpe from the University of Florida reestablished the blueberry breeding program.

Since low-chill cultivars were developed for warm climates, they are best suited to southern and coastal California. Their cold tolerance is unknown.

Southern highbush blueberry (low chill)

Most cultivars that have been developed are the result of crossing selections from the southern range of the native habitat of highbush *(V. corymbosum)* with other southern species, such as *V. darrowi*. Additional plant diversity and adaptation are provided by *V. angustifolium*, *V. ashei*, *V. constablaei*, *V. tenellum* Ait., *V. fuscatum*, and *V. myrsinites*. Most cultivars are self-fruitful, so only one cultivar is needed for adequate pollination. This trait has made southern highbush currently more popular than rabbiteyes. All of these cultivars require less chilling than do the northern highbush blueberries.

Early season

Bluecrisp. Berries firm, with excellent sweet flavor; 400 chill hours.

Jewel. Berries large, tart; plant upright to spreading; 200 chill hours.

Misty. Berries medium large, fragrant, sweet; often evergreen along the coast, beautiful maroon fall foliage in colder regions; 300 chill hours.

Sharpblue. Berries large, good color, excellent flavor; vigorous, productive; 200 chill hours.

Sapphire. Berries sweet, slightly tart; plant medium sized; 150 chill hours.

Star. Berries borne early, very large, medium blue, well flavored; plant is upright and moderately vigorous; 450 chill hours.

Snowchaser. Berries firm; 150 chill hours.

Bladen. Berries medium sized, light blue; vigorous, upright growth; 600 chill hours.

Millenia. Berries firm, large, powder blue; vigorous and slightly spreading; 300 chill hours.

O'Neal. Berries large, excellent color and flavor; spreading; 550 chill hours.

Windsor. Berries firm, large, powder blue; vigorous, spreading plants; 400 chill hours.

Midseason

Emerald. Berries medium blue, firm, mild; spreading habit, very productive; 250 chill hours.

Jubilee. Berries small, good flavor; upright and vigorous; 500 chill hours.

Sunshine Blue. Berries and plant small; ideal for containers; 150 chill hours.

Late season

Southmoon. Berries medium sized, outstanding flavor; good yields; 500 chill hours.

Ozarkblue. Berries firm, medium sized; vigorous, upright; 900 chill hours.

Santa Fe. Berries very large, light blue, sweet; vigorous, upright; 350 chill hours.

Rabbiteye blueberry

Cultivars classified as true rabbiteyes are derived wholly from the selections of the blueberry species *V. ashei* that were collected primarily from southern Georgia and northeastern Florida. The common name was established because the flower scar tends to look like a rabbit's eye. As observed in Florida and Georgia, rabbiteyes are not self-fruitful (unlike northern and southern highbush blueberries), so it is recommended to plant at least two rabbiteye cultivars for cross-pollination. Rabbiteye blueberries tend to ripen later in the season than southern highbush blueberries. This can sometimes be a problem in hot inland valleys during years where temperatures heat up early in the season.

Early season

Beckyblue. Berries firm; vigorous; 350 chill hours.

Bonitablue. Berries large; 400 chill hours.

Austin. Berries firm, flavorful; vigorous upright plants; 500 chill hours.

Prince. 350 chill hours.

Windy. Berries small, good flavor; moderately vigorous, upright, more susceptible to root rot than other rabbiteye cultivars; 300 chill hours.

Midseason

Premier. Berries firm, high yields; 550 chill hours.

Climax. Berries firm, flavorful; 450 chill hours.

Tifblue. Berries firm; very productive, sets fruit without a pollinator; 650 chill hours.

Late season

Centurion. Berries not as firm as other rabbiteye cultivars; upright, late producing; 600 chill hours.

Powderblue. Berries sweet, medium sized, excellent; 600 chill hours.

Brightwell. Berries excellent; 400 chill hours.

Baldwin. Productive, extended harvest period; 600 chill hours.

Woodard. Berries tart, firm; 350 chill hours.

Soil Requirements

Blueberries require a sunny location and do best in soil that is well drained and moist throughout the growing season. The pH should be from 4.5 to 5.5. Peat and muck soils are suitable, but contrary to popular belief, blueberries do not do well in wet soil or dense shade.

Soil conditions are often amended with organic matter in blueberry plantings to adjust the pH and improve drainage. Adjustment of soil pH is probably the most important step a blueberry grower can make in growing the crop. If the soil pH is below 4, incorporate lime or finely ground dolomitic limestone following recommended rates. If the pH is above 5.5, which is more likely, acidify the soil by adding one of the following amendments 1 year before planting:

elemental sulfur at a rate of approximately 1 to 2 pounds per 100 square feet to lower the pH one unit (e.g., from 6 to 5)

aluminum sulfate at a rate of 6 to 12 pounds per 100 square feet to lower the pH one unit (e.g., from 6 to 5).

It is highly recommended to plant blueberries on raised beds that are 8 to 18 inches high and 3 to 4 feet wide to provide additional drainage and aeration (see fig. 15.3).

Planting

Plant healthy 2- or 3-year-old plants from fall through winter and into early spring. Purchase bare-root or container-grown plants from a reputable nursery. Plants should be spaced approximately 2 to 3 feet apart in the row and 8 to 10 feet apart between rows. Set plants shallow, spreading the roots in all directions and covering them with 1 to 2 inches of soil. Firm the soil around the plants. Water thoroughly after planting, but do not fertilize at planting.

Strip off all flower buds or blossoms that appear the year the plants are set so that no crop is produced and the plant can grow more fruiting wood. If possible, set up blueberry rows to run north-south to take advantage of better sun exposure.

Figure 15.16

Blueberry bushes growing on a raised bed covered with sawdust. The bed is irrigated by two drip irrigation lines, which wet the entire surface.
Photo: P. M. Vossen

After planting, apply a surface mulch of well-decomposed compost, sawdust, wood chips, or some other suitable organic material to help keep the soil cool, conserve moisture, add organic matter, and control weeds. Like azaleas, blueberries have many shallow roots, so keep weeds and other plants away from the base. Also, do not dig or till soil around plants, as this will damage the root systems. Blueberry bushes are free-standing and require no trellis (fig. 15.16).

Fertilization

Four weeks after planting, apply 10-10-10 fertilizer at the rate of about 1 ounce (1½ tbsp) per plant. Sprinkle it evenly within 12 to 18 inches of the plant but not directly on the crown or stems. If possible, use mixes in which the potassium is supplied as potassium sulfate rather than potassium chloride. One of the best nitrogen sources is ammonium sulfate, which helps acidify the soil. As the plants reach mature size, apply the above fertilizers at a rate of ½ cup per plant 3 or 4 times per year, starting in the early spring when growth starts and at 2-month intervals. Organic-based fertilizers can also be used. Apply 1 pound of feather meal, blood meal, or fish meal per plant. Slow-release fertilizers also work very well.

Irrigation

Blueberries have a shallow, fibrous root system, so they are very susceptible to drought injury. A uniform and adequate water supply is essential for optimal growth. Plants require approximately 1 to 2 inches of water per week from May through September. The greatest demand for moisture occurs from berry swell through early harvest and when fruit buds are being formed, usually mid-June through August. Generally, two irrigations per week are adequate to maintain the proper moisture. Avoid overwatering blueberry plants because the roots are very susceptible to root rot. Blueberries prefer minisprinkler irrigation instead of drip irri-

Figure 15.17

Flower buds that are beginning to open appear at the tip of this blueberry shoot; the small, pointed vegetative buds below are still dormant. *Photo:* P. M. Vossen

gation since the minisprinklers wet more of the root system. Drip can be used but two lines should be run, one on each side of the plants. Minisprinklers are normally run two to three times per week; drip is run every day during the hot months of summer to maintain uniform soil moisture in the root zone.

Pruning

At planting time, prune all branches back by about 30% to encourage vigorous new growth. Young plants require little pruning for the first 2 to 3 years. Remove only dead or dying parts of branches and less-vigorous, spindly growth around the plant base to encourage vigorous, upright growth. To encourage good vegetative growth the first 3 years, blueberries are normally thinned of all fruit by removing the blossoms during bloom. After the third year, plants should be pruned annually. Fruit is produced on 1-year-old wood. If you prune too little, plants become twiggy, with small, spindly growth that produces small fruit on weak wood. Excessive pruning leads to fewer, larger berries, more new wood, but a poor crop. Pruning is most effective in the dormant season, when there are no leaves so you can see what you are doing; however, in mild climates, many cultivars may not defoliate. Early-fruiting cultivars (May or earlier) can, however, be pruned right after they have finished fruiting, which will encourage new growth almost immediately.

First, cut out any dead, damaged, or diseased wood. Keep the bush open by removing basal shoots that tend to crowd the inside of the plant or shoots that are smaller in diameter than a lead pencil. Leave larger shoots to develop into next year's fruiting wood. Cut out older wood (4 or 5 years old) that has small, weak lateral branches and few fruit buds. Cut these canes back to the ground or to a strong new side shoot. Limit the number of canes to one for each year of age of the plant, or a maximum of six to eight canes for old bushes.

If you remove one or two canes yearly and one or two new canes are produced, no canes will be over 4 to 6 years old. Remove small sucker shoots growing from the base of the plant and weak, twiggy wood, especially from the top of the plant, to allow light to reach the center. If plants overbear, remove some of the weakest 1-year-old wood and, if necessary, tip back some of the remaining 1-year-old wood. Then cut off about one-third of the flower buds, which can be distinguished from vegetative buds by their fatter, less pointed appearance. Flower buds appear at the tip of last year's growth (fig. 15.17).

Pests

For current, detailed information on blueberry pests, see the UC IPM Pest Management Guidelines: Caneberries, ipm.ucdavis.edu/PMG/selectnewpest.caneberry.html, and *Pests of the Garden and Small Farm* (Flint 1998).

Weeds. Because mulches are essential ingredients in good blueberry production, weeds are rarely a problem. Maintain a constant mulch around the base of the

plants by adding at least 1 inch per year to a total depth of approximately 3 to 4 inches.

Insects. Blueberries have very few problems with insect pests. Aphids can be present and will occasionally leave a sticky film on the berries. Orange tortrix and light brown apple moth occasionally feed on leaves but do very little damage. Root weevils, such as the black vine weevil, can sometimes feed on roots and stunt plants. Thrips occasionally feed on the developing fruit at the blossom stage and scar the fruit.

Diseases

Botrytis twig and blossom blight. This gray mold fungus can be a problem in prolonged rainy springs. Copper fungicides, if labeled for blueberries, can be applied at the beginning of petal fall and repeated at 10-day intervals during wet weather.

Phytophthora root rot. This root rot causes problems in poorly drained or overirrigated plantings. It can be prevented by planting on raised beds in very well drained soil and being careful not to overwater plants during the summer.

Birds. Many species of birds feed on blueberries. The principal species are starlings, robins, and bluebirds. The most effective method of control is to exclude them with bird netting.

Strawberries

Strawberries *(Fragaria × annanassa)*, are grown in backyards throughout California. Very specific planting dates combined with proper cultivar selection and planting location have led to an extremely successful commercial industry in California.

Backyard production can be enhanced considerably with better understanding of the horticultural characteristics of the strawberry plant. There are basically two types of strawberries: short-day cultivars and day-neutral cultivars. Short-day cultivars produce fruit when the days are cool and short in late fall, winter, and early spring. Day-neutral cultivars do not respond to day length and continue to produce flowers and fruit all year long, including in the summer, as long as temperatures do not get too high. Ever-bearers are generally considered synonymous with day neutrals; however, other locations outside California list specific cultivars as ever-bearers, many of which are not available in California.

If short-day plants are manipulated into receiving less than their required chilling (less than the number of hours of cold temperatures to ensure good fruiting), they will continue to flower and fruit over a very long time, as long as temperatures remain below about 75°F. This explains why you see major commercial strawberry production in the cool coastal regions of California.

Planting systems

Two planting systems—winter and summer—are used for California strawberries.

Winter planting

In southern California, plantings are made from late October through December using the current season's plants shortly after they are harvested from high-elevation nurseries. Because winters are mild, plants begin to grow immediately and fruit quite soon after planting.

Summer planting

Summer plantings are made in the Central Valley and occasionally in the coastal regions of California. Here, plants are planted from August in inland areas to October through spring on the coast, using plants dug from the previous winter that were stored at 28°F. These plants develop during the fall, winter, or spring then begin fruiting heavily in the spring or summer.

Spring planting

If short-day cultivars are planted in the spring (the beginning of long days), they will not flower and fruit adequately. All the plant's energy goes into producing

Figure 15.18

Spring-planted strawberries surrounded by black plastic for weed control. The runners and first flowers should be removed. *Photo:* P. M. Vossen

runners, and the plant does not produce fruit. In cool areas, day-neutral cultivars can be planted in spring for a summer crop if runners are removed early (fig. 15.18).

Cultivars

Experiment with various strawberry cultivars by planting several different ones on different dates to see which work best at your location.

Short-day strawberries

- Douglas. Berries very large, good color, good flavor, conical; early producer; typically winter planted in the first 2 weeks of October.
- Pajaro. Berries dark red, large, conical, good flavor; principally summer-planted cultivar in northern California in August and September.
- Chandler. Berries exceptional in flavor, color, and size; typically winter planted.
- Camarosa. Berries large, excellent flavor; winter planted.
- Sequoia. Berries large, soft, excellent flavor.
- Ventana. Berries very large, early; good producer, as early as late December when fall planted.

Day-neutral strawberries

- Albion. Berry medium sized, fine, balanced flavor; good tolerance of Verticillium, Phytophthora, and mildew; performs very well in the second year of production; one of the finest strawberries in California.
- Muir. Berries conical, better flavor than Selva and lighter in color.
- Irvine. Berries conical, medium sized, excellent flavor; winter planted.
- Fern. Berries medium sized, excellent quality; strongly day-neutral; excellent potential for home gardens because it produces all season long (July-November); planted in spring as soon as the ground is workable.
- Hecker. Berries abundant, small to medium sized, mild flavor, deep red; produces throughout the year; planted in late fall to spring.
- Portola. Berries very nicely shaped, good tasting; good producer, especially in areas a little farther from the coast.
- Quinault. Good flavor, decent yield; commonly purchased by home gardeners in hardware stores and retail nurseries; released from Washington state.
- San Andreas. Berries large with good flavor; extremely productive; good disease tolerance; recent release from the University of California.
- Seascape. Berries medium sized with decent flavor; lower yielding than recent releases; good tolerance of diseases and mites; a standard for organic growers for many years.

Soil Requirements

Strawberries perform best in sandy, well-drained soil on beds 6 to 8 inches high and 12 to 18 inches wide. Liberal amounts of well-decomposed organic matter applied at approximately 1 pound per square foot, worked into the ground before planting, help prolong the life of the plants and improve water-holding capacity. Strawberries require a soil pH in the range of 5.5 to 7.5.

Planting

After raking smooth and preirrigating beds, use a trowel to open a V-shaped hole about 6 to 7 inches deep. Place 1 level teaspoon of slow-release fertilizer, ammonium sulfate, or a concentrated organic fertilizer such as fish, feather, or blood meal in the bottom of each hole and cover with about 1 inch of soil to prevent root burn. Spread the roots out in a fan shape in the hole and cover with soil, firming it around the roots. Set plants at the exact level that they were growing in the nursery. Plants set too high will be weak, and plants set too deep will rot. Evenly space plants from 8 to 15 inches apart in the bed. Once plants are set, deep water to close pore spaces and establish the plant properly. Keep cultivation to a minimum because strawberry root systems are shallow. Mulch the planting with compost, sawdust, straw, wood chips, or grass clippings to control weeds.

Irrigation

Strawberry plants require consistent moisture throughout the growing season. Newly planted strawberry plants are generally overhead-irrigated to get good initial vegetative growth, then are switched to drip irrigation as the season progresses. Drip irrigation keeps moisture away from the fruit and prevents fruit rot.

Strawberries require 1 to 2 inches of water per week during the growing and fruiting season. With drip irrigation, they must be watered every day to maintain uniform soil moisture in the root zone.

Fertilization

Provide additional nitrogen fertilizer 6 weeks after planting if plant growth is weak and leaves are light green. Broadcast ammonium nitrate, or a similar nitrate fertilizer, or a concentrated organic fertilizer such as fish, feather, or bonemeal at a rate of approximately ½ pound per 100 square feet of row. Irrigate immediately after fertilization to move the nutrient material down into the root zone. Strawberries must be fertilized several times during the growing season, depending on the reaction of the plants. Poor vigor and light green leaves can indicate a need for fertilization. Slow-release fertilizers work very well in strawberry plantings because they provide their nutrients slowly over the entire season.

Before planting, strawberries can be fertilized organically by incorporating a legume cover crop or organic matter (compost or manure) at a rate of up to 500 pounds per 100 square feet of row. A large amount of these materials is needed because they have a low concentration of plant-essential nutrients. After planting, organic fertilizers should be broadcast under the plant twice per season and irrigated in.

Pruning

Trim off all runners as they develop, since the runners pull energy away from the mother plant and reduce fruit productivity and size. For spring-planted day-neutral cultivars, remove the first flowers that appear after planting to keep them from setting fruit that quite likely will rot and serve as a source of disease. Subsequent flowers can be left on for fruiting.

Pruning or mowing of short-day and day-neutral cultivars can be done at the end of the season in order to set up plants for a second season. This pruning is generally done in December or January and is followed by several fertilizer applications to encourage the plant to continue to grow. The pruning or mowing should not be done so low as to cut into the crown, and mowed leaves and stems should be moved away from the plant so as to not contaminate the area around it with diseases or insects.

Pests

For current, detailed information on strawberry pests, see the UC IPM Pest Management Guidelines: Strawberries, ipm.ucdavis.edu/PMG/selectnewpest.strawberry.html, and *Pests of the Garden and Small Farm* (Flint 1998).

Figure 15.19

Verticillium wilt on young strawberry plants. *Photo:* P. M. Vossen

Weeds

Traditionally, strawberries were mulched with straw to control weeds, but they can be mulched with other organic or inorganic materials placed around the plants to an adequate depth. Most modern and commercial plantings use clear plastic polyethylene mulches. Mulches offer the advantages of controlling weeds, keeping the roots cool and moist, and preventing direct contact of the fruit with soil organisms that can soften and rot the fruit before and after harvest. Plastic mulches are generally laid down in late winter over the plant tops and secured on the sides; then a hole is cut for each plant to grow through. Excessive cultivation may disturb strawberry plants because their root systems are shallow. Black or opaque plastics that prevent light from hitting the soil control weeds quite well. Clear plastic can be used as a soil mulch only if the soil has been sterilized to eliminate all weeds and weed seeds.

Insects, mites, and snails

Weevils. Several weevils attack strawberries above and below the ground. Most insecticides are ineffective against them. Abandoning the planting and moving to a pest-free area is recommended.

Spider mites. Spider mites produce webbing and stippling of the foliage, which stunts strawberry plants, reducing yields and fruit quality, especially when infestations take place early in the season. Dusty conditions contribute to spider mite populations. Spider mites can be controlled with the release of predatory mites or the regular use of insecticidal oils or soaps. Since the use of oils or soaps is not compatible with the use of predatory mites, gardeners should commit to using one or the other method and stay with it.

Lygus bugs. Lygus bugs are a plant bug that causes strawberry fruit to be misshapen by feeding around the developing achenes (the seed of the fruit). The bug is about ¼ inch long and is difficult to control through chemical means, so gardeners can pick them off by hand, making sure to keep all of the beneficial predator insects unharmed, including big-eyed bugs, minute pirate bugs, and damsel bugs.

Aphids. Aphids can stunt plants and cause damage to foliage and fruit during the early, cool part of the season. Generally, insecticidal soap applied at weekly intervals provides adequate control. They can also be knocked off with a water spray on a daily basis.

Leafrolling caterpillars. Saltmarsh caterpillar and cutworm feed on strawberry plants. They can be controlled effectively with registered insecticides, such as BT, and, since they generally occur in low numbers, they can be picked off by hand.

Slugs and snails. The rasping feeding of slugs and snails leaves a distinctive pattern on foliage and fruit and can be controlled with repeated applications of pesticides registered for slug and snail control or by handpicking.

Diseases

Verticillium wilt. Caused by a soilborne fungus that can cause strawberry plantings to die. Avoid land that has previously been planted in susceptible crops, such as tomatoes, potatoes, cucumbers, or peppers, or

nightshade weeds. Plant cultivars that are more tolerant of the disease, such as Sequoia, Albion, and San Andreas (fig. 15.19).

Root rot. Caused by several fungi, but mainly by *Phytophthora* spp., that attack the crowns and roots, particularly in poorly drained or overirrigated plantings. There is no control for affected plants. Prevent root rot by planting on raised beds and growing the more-tolerant cultivars Albion and San Andreas.

Botrytis fruit rot. A very serious rot of strawberry fruit, also known as gray mold. It is most serious during cool, wet weather. One of the best controls is to use plastic mulch, which separates the fruit from direct contact with the ground. Fungicides are essentially ineffective.

Powdery mildew. This white, velvety fungus is most frequently found on the younger leaves of susceptible plants, but it can advance over the whole plant when the leaves are dry, the relative humidity is high, and temperatures are cool to warm. Albion and San Andreas show excellent levels of resistance to this disease, which can also be controlled by the use of sulfur.

Currants and Gooseberries

Currants *(Ribes rubrum* and *R. nigrum)* and gooseberries *(Ribes grossularia* and *R. hirtellum)* are generally not grown in California, primarily because they need cold winters with adequate chilling and do not do well in hot, dry areas like the Central Valley. Furthermore, because these plants tend to flower early, they are exposed to damage from frost in areas that still freeze in the spring. Nevertheless, parts of the north coast and Sierra foothills have excellent climates for these fruits, and there they are hardy and fairly easy to grow. Black currants are an alternate host for the plant disease white blister rust. Those considering planting black currants should use cultivars that are completely resistant to this devastating disease.

Cultivars

Red currants (Ribes rubrum [R. vulgare])

Red Lake. Berries large, red, easy to pick; clusters well filled; long stems; considered to be the best and most productive cultivar.

Cherry. Clusters long, well filled, easy to pick; performs equally as well if not better than Red Lake in many areas.

Wilder. Clusters long, compact; consistently high yields during midseason, great resistance to leaf spot; widely planted commercially.

Black currants (Ribes nigrum), European black currant

Consort. Productive, self-fruitful, midseason; resistant to white blister rust.

Crandall. Berries dark red to black, attractive yellow flowers; American native; resistant to white blister rust.

White currants (Ribes rubrum [Ribes sativum])

White Imperial. Berries white with a pink blush, sweet, rich flavor.

White Grape. Berries large, white, good flavor; productive.

Green gooseberries

Invicta. Spiny, high yielding, disease resistant.

Pixwell. Berries medium sized, usually borne in clusters, pink when ripe, easy to harvest; moderately thorny; very productive and hardy; widely distributed by nurseries.

Red gooseberries

Poorman. Berries large, excellent flavor; very productive; less thorny than other cultivars; good for home use because of productivity and compatibility for fresh eating; recommended.

Fredonia. Berries medium sized, red-pink; late bearing; very productive.

Propagation

Currants and gooseberries are propagated by hardwood cuttings made in the fall after leaves have dropped. Medium-sized stem

tip cuttings 8 to 10 inches long from 1-year-old wood are preferred. Plant cuttings about 2 to 3 inches deep directly in the garden and keep the soil moist. Alternatively, store the cuttings in moist sawdust until spring, then plant them directly in the garden. Some cultivars are very slow to root and may require greenhouse mist and bottom heat along with rooting hormones. Most nurseries supply one or two cultivars of currants or gooseberries.

Soil Requirements

A fertile, well-drained loam soil with adequate organic matter is best for currants and gooseberries. These plants do not tolerate wet growing conditions; the roots will rot. Avoid light, sandy soil because of droughty conditions and high soil temperatures. Plant on raised beds as for caneberries or blueberries.

Planting

Space plants 2 to 4 feet apart in rows with 8 to 9 feet between rows. Gooseberry fruit is susceptible to scalding from direct sunlight, so these are best planted in areas of northern exposure. Given their susceptibility to mildew, they should also be planted in areas of good air circulation to keep the foliage dry. Currants and gooseberries are self-fruitful and do not require interplanting or cross-pollination. Place a heavy mulch around the base of the plants soon after the plants are in the ground to keep the soil cool and moist and prevent weed growth.

Fertilization

For most soil types, 1½ pounds of actual nitrogen applied per 100 square feet per year is adequate. It should be divided into two or three applications, beginning early in the spring when growth starts. Avoid using muriate of potash, which injures currants and gooseberries. Apply organic fertilizers and soil amendments at a rate of about 1 pound per square foot several months before planting and annually thereafter in the fall or winter.

Irrigation

Contrary to popular belief, currants and gooseberries are not drought tolerant and perform much better when the soil is kept uniformly moist throughout the growing season. Generally, 1 inch of water split into two applications per week from May through September is necessary for good berry production.

Pruning

Gooseberries and currants are upright bushes that tend to have crowded branches. Pruning to thin out branches keeps the plant more open. Begin pruning the third year after planting and aim to have nine main branches on each plant: three of the branches should be new; three should be 1 year old; and three should be 2 years old. Take out the oldest canes and leave three new ones to replace them each year.

Pests

Mites. Mites are a common problem on currants and gooseberries in the warm climate of California. Keep plants moist (not stressed) and apply overhead water to wash mites off.

Anthracnose. This fungus attacks leaves in wet spring weather. Keep the bush open so that good air circulation can dry the leaves quickly.

Powdery mildew. A major problem on gooseberries, powdery mildew appears as white, powdery blotches on stems, leaves, and fruit and can stunt plant growth if left unchecked. Sulfur and horticultural oils have proven to be somewhat effective in controlling powdery mildew on gooseberry.

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UC IPM Pest Management Guidelines: Caneberries. Updated regularly. UC IPM website, http://www.ipm.ucdavis.edu/PMG/selectnewpest.caneberry.html.

Temperate Tree Fruit and Nut Crops 16

Paul M. Vossen and Deborah Silva

Learning Objectives

Learn the basic principles about the growth and development of temperate tree fruits and nuts.

Become familiar with cultivars of selected temperate tree fruits and nuts that perform well in the home garden in various climate zones in California.

Learn the basic cultural requirements of temperate tree fruits and nuts.

Learn the basic principles of pest and disease management of selected temperate tree fruits and nuts grown in California.

Temperate Tree Fruit and Nut Crops

California is the most important state in the United States for production of temperate tree fruit and nut crops, leading the nation in production of apricots, peaches, nectarines, olives, plums, prunes, pears, almonds, walnuts, pistachios, figs, persimmons, pomegranates, and kiwifruit; annual production statewide exceeds 10 million metric tons. Many of these fruits and nuts can also be enjoyed from backyard trees throughout the state. They can make beautiful, practical additions to the home garden and landscape due to their striking flowers, edible harvest, and the shade that they provide. This chapter introduces selected temperate fruits and nuts that can be grown in the home garden in California. Although olives, figs, pomegranates, and kiwifruit are not, strictly speaking, temperate tree fruits, they are included in this chapter.

Types of Temperate Fruit and Nut Trees

Pomology is the technical term for the science and art of fruit culture. Scientists who study fruit and nut crops are known as pomologists. Scientists who study citrus and avocados, two subtropical evergreen tree fruit crops, are also pomologists, but they are said to specialize in subtropical horticulture. This handbook features three chapters on fruit trees: one on citrus (chapter 17), one on avocados (chapter 18), and this one on temperate tree fruits and nuts.

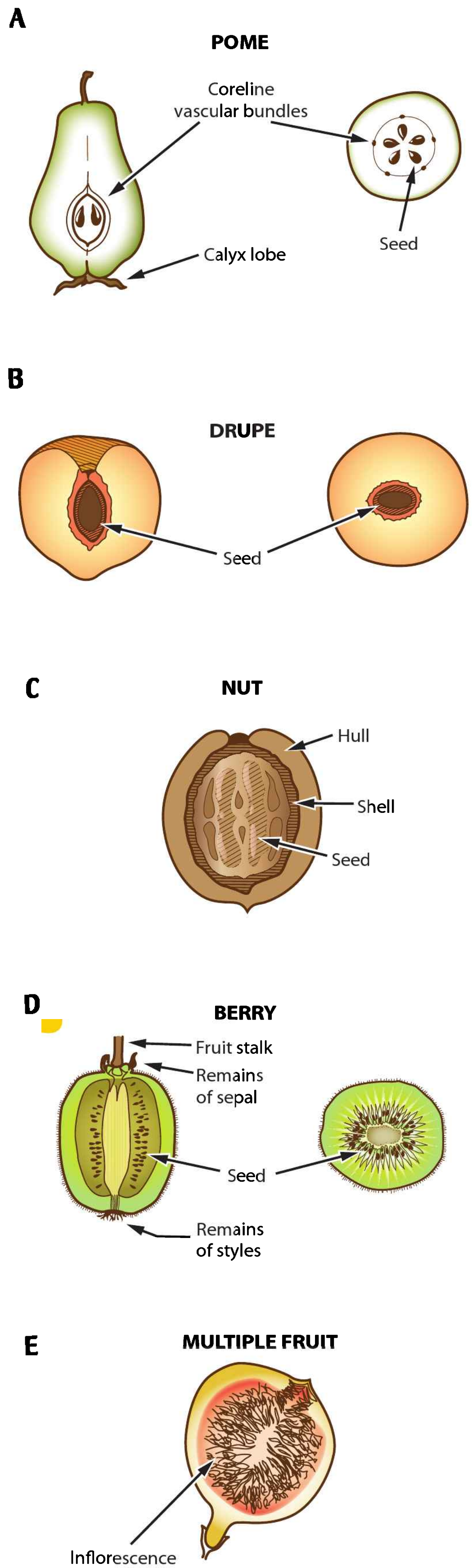
The diverse fruit and nut crops featured in this chapter are temperate zone trees (except kiwi, which is a vine) native to climates with distinct summer-winter patterns. The majority are deciduous woody perennials, which means that the trees lose their leaves and go into dormancy (quiescence) in autumn and must receive a specific number of winter chilling hours below 45°F during winter to resume growth, flower normally, and set fruit in the spring. Since many locations in southern California lack sufficient winter chill, home gardeners in that part of the state must be careful to select low-chill cultivars adapted to the subtropical climate of those regions. Cultivars adapted to all regions of the state are discussed in this chapter.

Temperate tree fruits and nuts grow best in latitudes between 30° and 50° worldwide, which encompasses most of the United States. Most commercial production is confined to California and a few regions in about 11 other states (the Pacific Northwest, the eastern shores of the Great Lakes, a narrow belt along the Appalachian Mountains, the Northeast, and the southeastern states). Successful production can be extended to lower latitudes if the site is sufficiently high in elevation to provide adequate chilling. Olive, which is a subtropical fruit, is the exception; olives are evergreen and will not tolerate temperatures below 22°F, yet they require some cold temperature in the winter to develop good bloom and set fruit.

The fruit, nut, and miscellaneous fruit crops grown in California featured in this chapter include the following fruit types.

Figure 16.1

Sections of selected fruits and nuts: (A) pome (pear); (B) drupe or stone (peach); (C) nut (walnut); (D) berry; (kiwi); (E) multiple fruit (fig). *Source:* After Westwood 1993, p. 71 and Hasey et al. 1994, p. 88.



Pome Fruits

Apple *(Malus domestica)*, pear *(Pyrus communis)* and Asian pear *(P. serotina, P. pyrifolia)*, and quince *(Cydonia oblonga)* are grouped together by botanists because their fruit type is a pome (fig. 16.1A). The flowers of pome fruits arise conjointly above the ovary, and the fruits are derived from the fusion of the ovaries, calyx cup (sepals), and floral tube. The fleshy part of the pome fruit that is consumed is non-ovarian calyx (sepal) and receptacle tissue. Less widely planted pome fruits grown in California, such as the evergreen loquat *(Eriobotrya japonica)*, are discussed in some of the resources listed in the bibliography at the end of this chapter. Pome fruits and the stone fruits (listed below) are members of the Rosaceae family.

Stone Fruits

Apricot *(Prunus armeniaca)*, sweet and sour cherry (*Prunus avium* and *P. cerasus*, respectively), nectarine and peach *(P. persica)*, European plum and prune (dried European plums, *P. domestica*), and Japanese plum *(P. salicina)* are stone fruits belonging to the genus *Prunus*. Their fruit is botanically known as a drupe (fig. 16.1B), a one-seeded fruit derived entirely from an ovary with a stony endocarp containing the seed. Almonds *(P. dulcis*, formerly *P. amygdalus)* also belong to the genus *Prunus* and are technically stone fruits, but this chapter includes almonds with the nut crops because they are consumed as nuts. Plumcots, pluots, and apriums are interspecific hybrids between the various plum and apricot species.

Nut Crops

Almond *(Prunus dulcis)*, chestnut (*Castanaea* spp.), filbert (*Corylus* spp., also known as hazelnut), pecan *(Carya illinoensis)*, pistachio *(Pistacia vera)*, English, or Persian, walnut *(Juglans regia)*, and black walnut *(J. hindsii)* are, with the exception of almonds, hard, woody, usually one-seeded fruits derived from the fusion of ovary and perianth (petals and sepals). Chestnuts are

also different in that the edible portion is a high-carbohydrate, low-oil fruit/nut, unlike the other nuts (fig. 16.1C).

Vines

Kiwifruit *(Actinidia deliciosa* and *A. chinensis)* is classified as a berry, a multiseeded fruit derived from a single ovary (fig. 16.1D). Other vine fruits are discussed in chapters 14, "Grapes," and 15, "Berries."

Other Tree Fruits

Fig *(Ficus carica)*, olive *(Olea europaea)*, persimmon *(Diospyros kaki)*, and pomegranate *(Punica granatum)* do not fit into the above categories, yet they are important trees in the home garden in California. The fig, a multiple fruit (fig. 16.1E), is derived from the fusion of ovaries and receptacles (the part of the flower stalk that bears the floral organs) of many flowers. The olive fruit is a drupe; the persimmon is technically a berry with four sepals. Pomegranate is a small tree or shrub with large, apple-sized fruit that are covered in a leathery skin. The seed have a fleshy seed coat called an aril that can be eaten.

Growth and Development

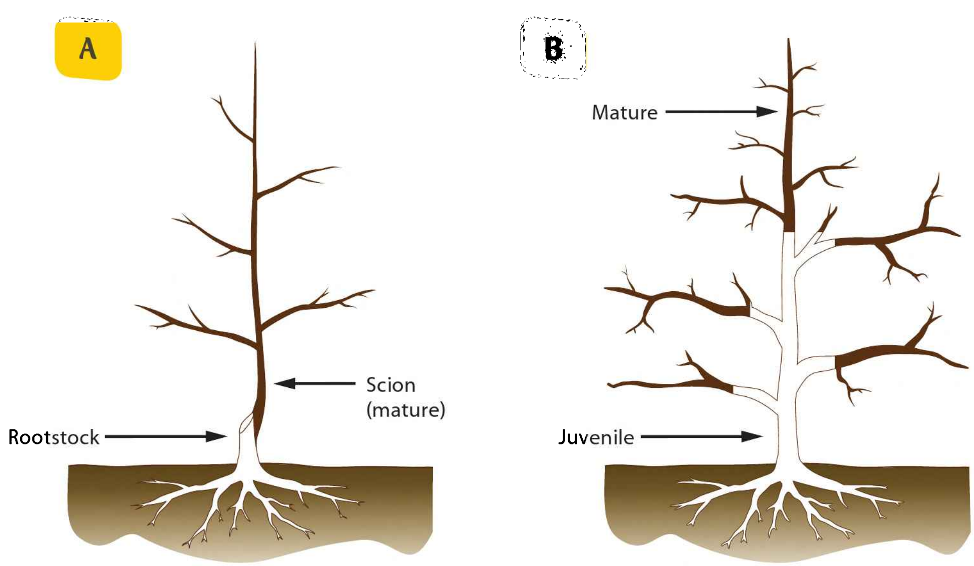
Since fruit and nut trees are perennials, the cultivars chosen and their location in the home landscape are long-term decisions requiring careful planning and knowledge of the trees' growth and development habits.

Scions and Rootstocks

Fruit and nut trees usually consist of a scion cultivar grafted onto a rootstock cultivar (fig. 16.2A). The rootstock cultivar makes up the lower few inches of the trunk and the tree's roots. The scion cultivar makes up the rest of the trunk and all the branches, leaves, and fruit. Rootstocks are selected for their improved disease and nematode resistance, tolerance to adverse soil conditions, nutrient uptake, cold hardiness, and favorable influence on the performance of the scion cultivar, including tree size (dwarfing effects), fruit quality (sugar-to-acid ratio, flavor, texture, size), and productivity (yield efficiency). (For the effects of various rootstocks on scion cultivars and recommended combinations, see the section "Cultivars" in this chapter.)

Figure 16.2

Grafted and ungrafted fruit trees. (A) Grafted tree is composed of a scion and rootstock. It is all mature wood above the bud union. (B) Seedling tree has juvenile wood from the base up into the crown, a transition zone midway up trunk, and mature wood in the top and branch ends. *Source:* After Westwood 1993, p. 218.



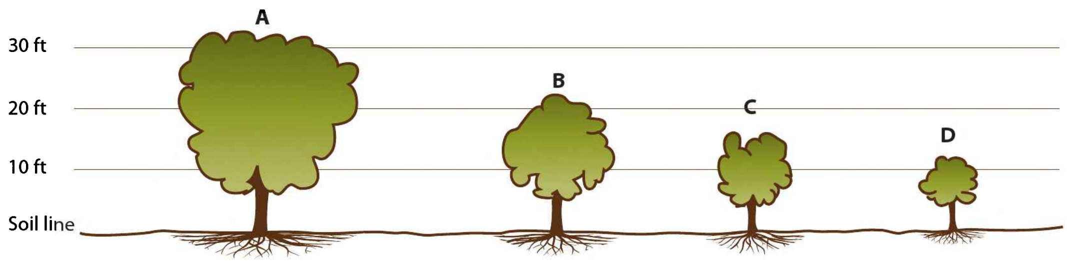


Figure 16.3

Size control in temperate fruit trees. (A) Standard variety with no size control; (B) and (C) standard variety on semidwarfing rootstock or semidwarf variety; (D) standard variety on dwarfing rootstock or genetic dwarf variety.

Scions are selected for the quality of their fruit, as a source of pollen for cross-pollination, and good branch structure. By grafting or budding the scion cultivar onto a selected rootstock, we are assured of an exact duplicate of the mother scion, with the same delicious fruit and good growth habit. Some trees, such as olives and figs, do not need rootstocks and are simply grown from rooted scion cuttings.

Size Control in Fruit and Nut Crops

Home gardeners in California have the option of growing cultivars as various sizes of trees:

- standard-sized trees grow to the typical size of the cultivar, about 15 to 35 feet tall (fig. 16.3A)
- semidwarf trees grow to about 12 to 20 feet tall, about two-thirds of standard size (fig. 16.3B–C)
- dwarf trees attain about half of the standard size, approximately 8 to 12 feet tall (fig. 16.3D)

Standard-sized trees of the taller temperate species, such as walnut, pecan, chestnut, almond, olive, apple, pear, and sweet cherry, can double as shade trees if space is available, but a ladder will be needed for pruning and harvest. On the other hand, dwarf cultivars permit growing a wider array of fruits in limited space. Another advantage is that dwarf and semidwarf trees typically begin to bear fruit 1 to 3 years earlier than standard-sized trees. Also, pruning, thinning, and harvesting them can be done without ladders and should take less time per tree.

The lower-vigor dwarf trees require more care, such as frequent irrigation, careful pruning, and better fertility, than do standard rootstock trees with greater size and vigor. Some dwarfing rootstocks are shallow rooted and inadequately anchored compared with other rootstocks and may require staking. Standard-sized trees are much more able to survive adverse conditions and neglect. Neglected dwarf and semidwarf trees often become stunted (poor shoot growth) or full of fruiting spurs without any new vegetative growth. For the first couple of years, this is not a problem, but the fruit eventually becomes smaller on old wood, and the tree becomes less fruitful without adequate new growth.

Size reduction in temperate fruit trees is typically achieved in one of the following three ways.

Dwarfing rootstock

Normal-growing cultivars can be grafted onto rootstocks that have dwarfing effects on overall tree size. The dwarfing effect is usually a physiological response as the limited vigor of the rootstock is transferred to the scion. In some cases, dwarfing is also caused by a slight incompatibility between the scion and rootstock. Unfortunately, only a few species of fruit trees have reliable dwarfing rootstocks:

Apples: E. Malling Series and MM Series from England; EMLA Series, virus-free plants from England; P Series from Poland; V Series from Vineland, Canada; Bud Series from Russia; MAC Series from Michigan

Pear: Quince (40–50% dwarfing) for specific cultivars only, or the use of an interstem between the quince rootstock and scion cultivar

Cherry: Giesla Series (varying degrees)

Peach and nectarine: Citation (most cultivars)

Apricot, aprium, pluot, and plumcot: Citation (slight dwarfing effect).

Almond, plum, Asian pear, olive, persimmon, fig, pomegranate, walnut, pecan, and chestnut: none

Genetic dwarfs

In peaches and nectarines, fruiting cultivars have been bred to include a dwarfing gene that produces a tree with short internodes that grows to about one-third the size of a normal tree. In apples, mutations of standard cultivars that have compressed growth and produce an abundance of fruiting spurs are called spur-type trees. Genetic dwarf and spur-type trees are usually grafted onto a standard rootstock. Genetic dwarf trees do not usually have smaller fruit, but they may set more fruit per given area, as the shoots have shorter internodes and compressed fruit buds. Because fruit set can far exceed the reduced canopy's capacity to size the fruit, home gardeners must be careful to thin genetic dwarf trees properly (see the section on fruit thinning later in this chapter).

Interstem

Normal-growing cultivars can be grafted onto standard or semidwarf rootstocks, with the interstems grafted between the scion and rootstock, producing dwarfing effects on overall tree size. Doubling of the dwarfing effect by using genetic dwarf or spur-type cultivars grafted onto dwarfing rootstocks or interstems produces extreme dwarfing in trees. These combinations are generally not viable because the trees are too small and lack sufficient vigor.

Dormancy and Winter Chill

The growth of deciduous fruit and nut trees follows an annual pattern that changes with the seasonal transitions in the surrounding environment. Typically, these fruit and nut trees grow rapidly during the spring and first half of the summer. Later in the season, the growth rate declines. In the fall, growth stops as day length and temperature decrease, the trees drop their leaves, and growth inhibitors (hormones) are produced that prevent the tree from growing. In the winter, the tree's internal processes are in a state of rest known as dormancy due to the presence of these growth inhibitors. During dormancy, growth does not occur even under ideal temperature conditions. This prevents the trees from beginning to grow during atypical periods of warm weather only to become damaged by freezing temperatures later in the winter or early spring.

Dormancy is broken when sufficient cold temperature breaks down the growth inhibitors in the tree. This cold period is called chilling, winter chill, or sometimes vernalization. A specific number of cumulative hours of chilling (temperatures lower than 45°F) is required to break dormancy; the number of hours differs from cultivar to cultivar. Once the cultivar has accumulated the appropriate number of hours of chilling, active growth resumes in the spring, but only after trees are exposed to temperatures warm enough for natural growth processes to begin. Most of northern California receives between 800 and 1,500 hours of chilling each winter. Southern California and the coastal areas in northern California may receive only 100 to 400 hours. It is primarily the lower elevations in southern California that have very few hours of winter chilling and require special care and cultivar selection; most higher-elevation areas of southern California receive adequate chilling hours.

Temperate trees and shrubs grow best in climates in which the winters are warm enough that plant tissue is not killed from extreme low temperatures but cool enough that buds receive adequate chilling to break dormancy. Flower and shoot buds of deciduous fruit trees and olives grow normally in the spring only after exposure to sufficient winter cold. After winters with inadequate chilling, the plants leaf out late in the season (delayed foliation), blossoming is prolonged, buds may deteriorate or drop, and fruit set is typically reduced.

Winter chilling index

The number of hours below 45°F is a fair index of the adequacy of winter chilling. Both the absolute number and distribution of the hours below 45°F must be considered. The chilling requirements of selected temperate tree fruits and nuts are given in table 16.1. December and January are usually the most critical months. If each of these months has approximately 400 hours below 45°F, and if these hours are distributed fairly evenly, troubles related to mild winters are less likely. Regular accumulation of chilling weather is essential for many cultivars to perform optimally. Periods of a few days to a week or more of warm weather may offset or reduce the effectiveness of accompanying periods of good chilling weather. Greater seasonal totals are usually necessary in years or districts with interrupted periods of adequate low temperatures and warm, sunny days. Cloudy or foggy weather that maintains temperatures below about 60°F during the day and 45°F at night is often necessary in parts of California to achieve adequate chilling hours.

Low-chill cultivars

Over the years, plant scientists and breeders around the world have been selecting and developing cultivars that require less chilling: many require 300 hours or less of temperatures below 45°F. The development of these low-chill cultivars has extended the range of climates and latitudes in which temperate tree fruits and nuts can be produced. Certain cultivars of apple, pear, apricot, nectarine, peach, Japanese and hybrid plums, and kiwifruit are reported to have low chilling requirements (see the section "Cultivars" in this chapter). In general terms, the relatively low chilling requirements of quince, fig, persimmon, almond, olive, chestnut, and pecan have enabled many cultivars of these fruits and nuts to thrive in areas with low winter chill. However, sweet and sour cherries, filbert (hazelnut), and pistachio are not suitable for the low elevations of southern and coastal California because of the lack of low-chill cultivars.

Table 16.1.

CHILLING REQUIREMENTS OF TEMPERATE TREE FRUITS AND NUTS

Type of fruit	Approx. hours at < 45°F needed to break dormancy	Equivalent time in days if continuously exposed to 45°F or below
almond	250–500	10–20
apple*	500–1,000	20–40
apple (low-chill)	400–600	16–24
apricot*	300–800	12–32
cherry, sour	1,200	48
cherry, sweet	700–800	28–32
chestnut	400–500	16–20
fig	100	4
filbert (hazelnut)	800	32
kiwifruit*	300–800	12–32
olive	200–300	8–12
peach/nectarine*	500–800	20–32
pear*	700–800	28–32
pear (Asian)	350–450	14–18
pecan	250	10
persimmon	100–200	4–8
pistachio	800	32
plum, American*	3,600	144
plum, European*	600–800	24–32
plum, Japanese	250–700	10–28
plumcot	400–600	16–24
pomegranate	100–150	4–6
quince	300	12
walnut, Persian	500–700	20–28

Note: *See the section "Cultivars" in this chapter for low-chill cultivars of these fruits, which have been reported to require < 300 hours of temperatures < 45°F to break dormancy.

Bud Development and Classification

During the growing season, some buds and branches are actively growing at the tips, but most of the buds farther down the shoots are at rest. In most cases, latent buds are controlled by an inhibiting hormone called auxin produced by the apical bud (the terminal growing point). Auxins are strongly influenced by gravity. They travel down the shoot and prevent the lower buds from growing. Buds in vertical shoots are more strongly affected by gravity because of the orientation of the shoots; therefore, those shoots tend to grow strongly from one apical bud and become dominant.

Pruning off the apical bud (a heading cut) can temporarily release the lower lateral buds from inhibition by the auxin, causing the growth of multiple lateral shoots (the bush effect). These shoots are typically less vigorous because more buds grow than just the bud at the apex of the branch. The lower vigor of these lateral shoots results in the development of more flower buds and increased fruitfulness. Home orchardists can influence the development of branches and flowers through careful pruning techniques and by bending upright branches into more horizontal positions, usually at 45° to 60° angles, positively influencing both fruitfulness and vegetative vigor.

Buds are classified by their activity level (active or latent), their function (vegetative or flowering or both), and by position or origin on the stem (terminal, lateral, or adventitious). Active buds produce the current season's shoots as terminal growth or as short lateral shoots known as spurs. Active buds may also develop into flowers. Buds that do not become active are latent and can be induced to grow by pruning. Buds that give rise to shoots are known as vegetative buds. Buds that give rise to flowers are called flower buds. Buds that give rise to both flowers and leaves are called mixed buds. Shoots arising from mixed buds can bear their flowers terminally or laterally. New growth arising from positions where buds are not normally found came from adventitious buds. Suckers, strong vertical shoots arising from the roots, and water sprouts, strong upright shoots arising from older branches, are the most common examples of growth from adventitious buds. When large branches are topped, the new shoots that grow from callus tissue formed at the wound also come from adventitious buds.

Flower Bud Formation

Even though the grafted or budded nursery tree is adult tissue (see fig. 16.2A), trees may not flower immediately after planting. They usually go through a vegetative phase called juvenility. The transition to becoming a mature flowering tree is controlled by complex hormones and is influenced by carbohydrate accumulation, light exposure, age, vigor, and nitrogen nutrition. Once a tree does begin flower development, cultural practices (pruning, fruit thinning, and fertilizing) and environmental conditions can influence additional flower bud formation during a particular season.

In most cases, it is desirable for trees to grow vigorously without fruit formation for the first 2 to 3 years so that they can fill their allotted space in the garden or orchard. Trees grow more slowly after they begin bearing fruit because they are putting their energy into fruit production. This is a simple energy displacement: fruit is a demanding sink for carbohydrates (sugars) produced by the leaves. The flow of most of the energy source to the fruit reduces that available for shoot growth. Once they begin to fruit, it may be difficult to get trees to grow significantly and fill their space, especially genetic dwarfs, spur-type trees, or trees with dwarfing rootstocks. In most cases, neglected trees become stunted and never reach their full growth or fruit-bearing potential. These trees should be replaced, and the new tree should be encouraged to grow vigorously for the first few years through adequate water, fertilization, pruning, and weed control.

During the early stages of tree development, minimal pruning favors flower bud formation and earlier fruit set because more lower-vigor shoots are produced. Over time, however, unpruned trees develop thick canopies, which limits light penetration into the tree and results in poor flower bud formation and poor fruit set in all but the uppermost portions of the tree. Young buds that are exposed to full sunlight produce flowers with greater longevity and larger fruit. Unpruned trees do not develop as much sun-exposed renewal (new) wood for future flower and fruit development. Pruning is discussed more fully in its own section later in this chapter.

Adequate nitrogen fertilization is important in maintaining proper tree vigor and flower bud formation. Excessive nitrogen can create strong vegetative growth in fruit trees, which reduces light penetration into the canopy and results in less flower bud formation and lower fruit yield. Therefore, avoid oversupplying nitrogen (not only because it can reduce fruit and nut yield, but also because it can pollute groundwater resources if leached). Inadequate nitrogen fertility, the opposite extreme, can also be a problem for fruit and nut trees. It usually appears as yellow or light green leaves and low tree vigor, preventing strong shoot formation and causing more tree sunburn. Nitrogen fertilization is discussed more fully in the section on fertilization later in this chapter.

Alternate Bearing

Alternate (biennial) bearing, the term used to describe fruit trees that produce a heavy crop one year and a light crop the next, is mostly caused by alternate blooming. In years with heavy bloom, excessive fruit may be set. Between the full bloom stage and the small fruit stage, most fruit trees are producing flower buds for the next year. In most tree crops, a large crop on the tree produces hormones that send a chemical message to the developing buds not to initiate flowers the following year. Consequently, next year's bloom is light, fewer fruit have an opportunity to set, and the yield is much smaller. During the light cropping year, many flowers are initiated in the buds, which leads to heavy flowering the following year, more fruit set, and an alternate bearing cycle.

The most effective way to reduce alternate bearing and increase final fruit size is to hand-thin the tiny fruit within 30 to 45 days after full bloom, when the fruit reach ⅜ to 1 inch in diameter. The advantage of early thinning is that the fruit removal occurs during or prior to flower initiation and therefore has a positive influence on blooming the next year. Early thinning also provides the maximum benefit for fruit size on the remaining fruit in the current year. Early thinning reduces the number of fruit acting as sinks for a longer time, making more food from photosynthesis available for the remaining fruit.

Pruning can also have an impact on alternate bearing. In peaches and nectarines, removal of almost half of last year's growth effectively thins the canopy and leads to more even cropping. In olives, pruning is done during bloom every other year in the season that is expected to have a large crop. Trees with heavy bloom are pruned more than trees with light bloom to even out the crop from year to year.

Flowering and Fruiting Habits

It is useful to understand the flowering habits of deciduous fruit and nut trees because flowers are essential to fruit production (tables 16.2–16.3). This information can also influence fruit thinning, pruning, fertilization, and other cultural practices.

Pome fruits

Apple flower buds are usually borne terminally on shoots or short spurs that are 2 years old and older, but they may occasionally be borne on lateral buds of 1-year-old shoots (see table 16.2 and fig. 16.4). Apple blossom clusters contain five

flowers. Pear blossom clusters contain seven or eight flowers that are borne on shoot terminals and on short spurs that are 2 years old and older. Most European pears are not alternate bearing and require little or no fruit thinning. Unlike apples and pears, the quince flower bud contains only one flower. Pome fruit spurs are typically productive for about 5 to 10 years given good light and growing conditions. Pruning out a few branches with old spur systems each year encourages new branch and spur formation, ensures continued productivity, and produces larger fruit. Anatomically, pome flowers are perfect, containing both male and female parts, but most require pollen from another cultivar (cross-pollination with the help of honey bees) in order to set fruit (see the section on pollination require-

Table 16.2.

TIME OF FLOWER INITIATION AND FULL BLOOM IN SELECTED TREE FRUIT AND NUT CROPS

Flower type	Beginning of induction or initiation	Flowers borne on	Season of full bloom relative to season of initiation
Pome fruits			
apple	mid-Jun–mid-Jul	terminal buds, 2-year spurs or lateral buds, 1-year shoots	next spring
pear	early Jul–early Aug	terminal buds, 2-year spurs	next spring
quince	early spring–Jun	terminal shoots, current growth	same spring
Stone fruits			
almond	mid-Aug–mid-Sep	lateral buds, 1-year shoots	next spring
apricot	early Aug	lateral buds, 1-year shoots, 2-year spurs	next spring
cherry, sour	mid-Jul	lateral buds, 2-year spurs	next spring
cherry, sweet	early Jul	lateral buds, 2-year spurs	next spring
peach and nectarine	late Jun–late Jul	lateral buds, 1-year shoots	next spring
plum, Japanese	mid Jul–early Aug	lateral buds, 1-year shoots, 2-year spurs	next spring
prune	late Jun–mid Aug	lateral buds, 1-year shoots, 2-year spurs	next spring
Nuts			
filbert, female	Jul–Sep	lateral buds, 1-year shoots	next winter
filbert, male	May	lateral buds, 1-year shoots	next winter
pecan, female	early spring	terminals of current shoots	same season
pecan, male	early summer	lateral buds, 1-year shoots	next spring
pistachio	late Apr	lateral buds, 1-year shoots	next spring
walnut, female	late summer	terminals of current shoots	next spring
walnut, male	early summer	lateral buds, 1-year shoots	next spring
Vines			
kiwifruit	late summer	lateral buds, 1-year canes	next spring
Miscellaneous fruits			
fig (crop 1)	late summer	lateral buds, 1-year shoots	next spring
fig (crop 2)	early summer	lateral buds, current growth	same season
olive	late winter	lateral buds, 1-year shoots	next spring
persimmon	Jul	lateral buds, 1-year shoots	next spring

Figure 16.4

Pome fruit flowering habits. *Source:* After Westwood 1993, p. 220.

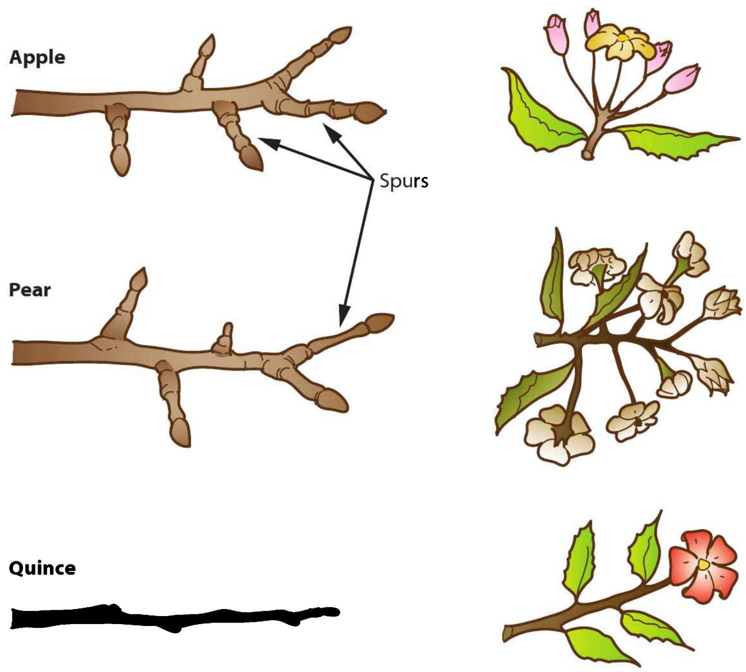


Table 16.3.

GROWTH AND DEVELOPMENT OF SELECTED POME AND STONE FRUIT TREES

Fruit type and rootstock	Pollination requirements*	Mature height (ft)†	Mature spread (ft)†	Years to bearing after planting	Yield per tree per season (bu)	Bearing period
apple						
dwarf	SS or PSF	6–10	8–10	2–3	3–5	Jun–Nov
semidwarf	SS or PSF	10–14	14–18	4–5	5–10	Jun–Nov
standard	SS or PSF	15–30	20–25	5–7	10–25	Jun–Nov
apricot	PSF	20–25	18–20	4–5	2–4	Jul
cherry, sweet						
semidwarf	SS	14–20	14–18	4–6	20–40 qt	May–Jun
standard	SS	25–35	20–25	4–6	30–60 qt	May–Jun
peach and nectarine						
genetic dwarf	SF	3–6	5–8	3	1–1.5	Apr–Oct
standard	SF	8–18	18–20	4	3–5	Apr–Oct
pear (Asian)						
standard	SS	8–16	12–16	3–4	5–6	Aug–Oct
pear (European)						
dwarf	SS	10–15	10–12	3–4	1–3	Aug–Oct
standard	SS	25–40	20–25	5–7	4–6	Aug–Oct
plum						
standard	SS or PSF	18–22	18–20	4–5	3–5	NA
European	PSF	18–22	12–15	3–5	3–4	Jun–Oct
Japanese	SS	20–25	10–12	3–5	3–4	Jun–Oct
American	SF or PSF	15–20	10–12	3–5	variable	Jun–Oct

Notes:

*PSF = partially self-fertile, which means that a heavier fruit crop is set when two or more cultivars are planted nearby; SF = self-fertile, which means that one cultivar is needed for pollination; SS = self-sterile, which means that two cultivars are needed for pollination. Exceptions to these general statements about specific fruit types will occur with some cultivars.

†Summer and winter pruning influence tree height and spread.

ments, below; see also table 16.3). Flower buds for all the pome fruits are initiated in early summer for next year's crop, usually within 45 days of full bloom.

Stone fruits

Almond, peach, apricot, plum, and cherry flower buds (see table 16.2 and fig. 16.5) are quite different from the flowers of pome fruits:

Almonds have solitary flowers in a lateral position. They are borne primarily on short spurs that live for 2 to 3 years, but also on 1-year-old shoots. Almonds require only moderate annual thinning to renew fruiting wood.

Peaches and nectarines have solitary flowers that are always in a lateral (not terminal) position and are borne on 1-year-old shoots (last year's growth). Each node usually contains three buds (two flower buds on each side of a vegetative bud). Peaches and nectarines can bloom and bear fruit the second or third year after planting. They must be pruned fairly heavily each year to encourage an abundance of new shoots to bear flowers and fruit the following season.

Apricots also have single, simple buds (one flower in each bud), but they can be born laterally on either 1-year-old shoots or on older, short spurs. The spurs are productive for 3 to 5 years. Apricots should be pruned moderately each year to encourage some new growth on which new spurs can develop.

Plums and prunes have flower buds with multiple flowers in each bud borne laterally on spurs 2 years old and older, and occasionally on 1-year-old wood. Each bud produces one to five flowers, with terminal buds being vegetative. Spurs live for 4 to 6 years. Plum and prune trees must be pruned moderately each year to renew the fruiting spurs.

Sweet and sour cherry flowers also have buds with multiple flowers that are borne in clusters of two to six buds on spurs that are at least 2 years old. Cherry spurs live for 5 to 10 years, so these trees need modest pruning each year to ensure enough new growth to replace old spurs.

The flowers of stone fruits contain both male and female parts, but most cultivars of plum, plumcot, aprium, cherry, and almond as well as some apricots require cross-pollination (see table 16.3), and bees to do the pollinating. Peach, nectarine, and most apricots do not require cross-pollination. Like pome fruits, floral initiation begins in summer for the following year's crop, so growing conditions during the summer can influence the health and abundance of next year's flowers and fruit.

Figure 16.5

Stone fruit flowering habits. Note that flowers are always borne on 1-year-old shoots. *Source:* After Westwood 1993, pp. 220–221.

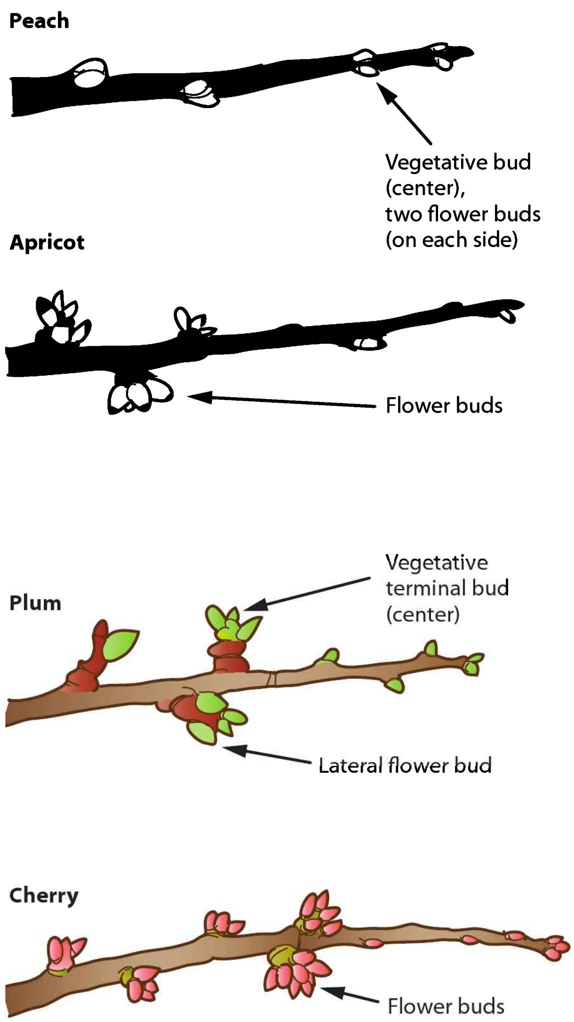
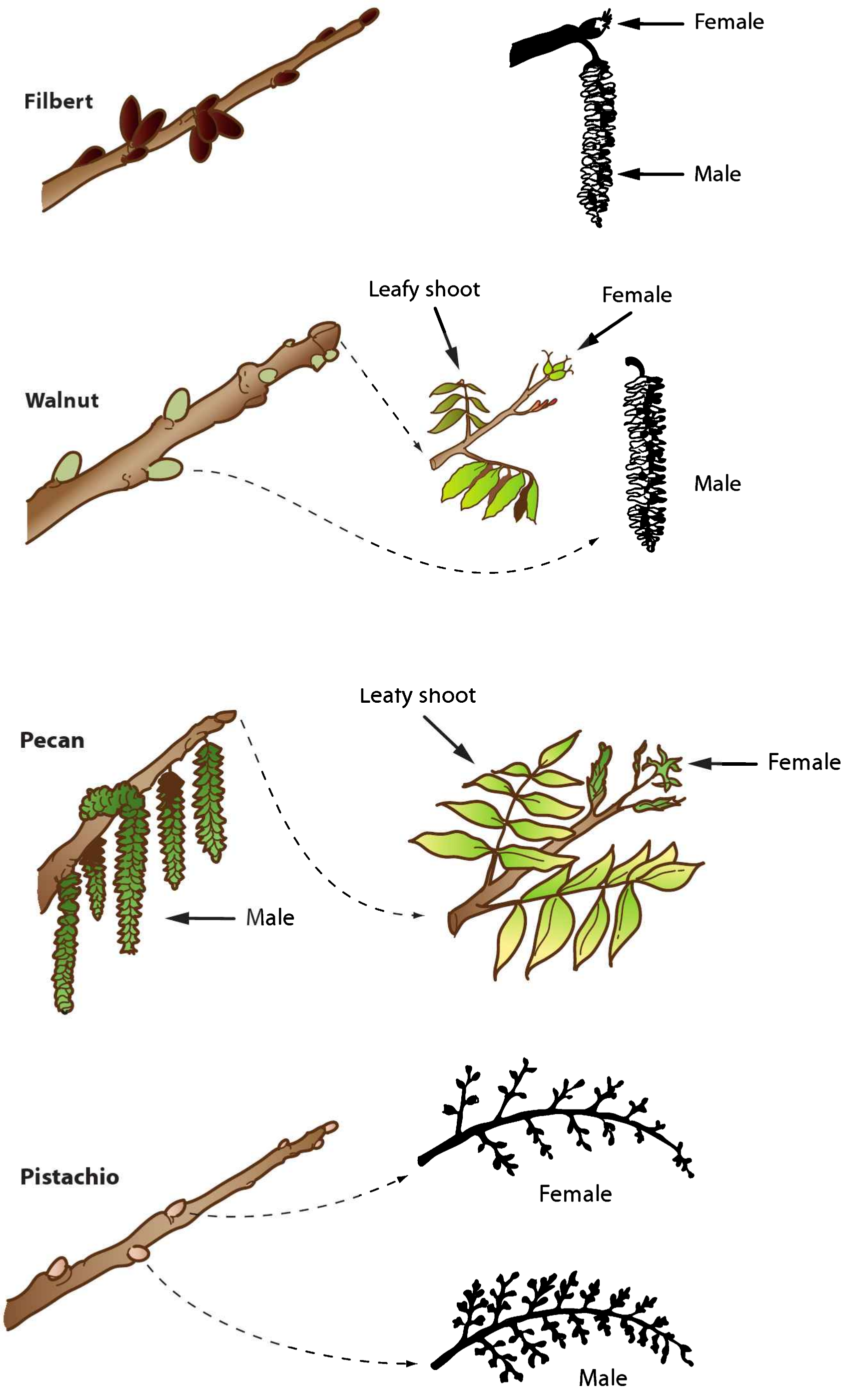


Figure 16.6

Flowering habits of selected nut crops. *Source:* After Westwood 1993, pp. 224–225.



Nut crops

Chestnut, filbert (hazelnut), pecan, and walnut are monoecious, which means that they have separate male and female flowers on the same tree (see table 16.2 and fig. 16.6). They often require a pollinator cultivar, as the male and female flowers do not always bloom at the same time. Walnuts and pecans are similar in that the male catkins are borne in lateral buds on 1-year-old wood (last year's growth), and female flowers are borne terminally and laterally on the current season's growth. The female flowers have no petals and consist of a large, reflexed stigma attached to an ovary. Walnut, pecan, pistachio, chestnut, and filbert are pollinated by wind. In filbert, the male catkins and female flowers are borne on lateral buds of 1-year-old wood. Female flowers have no petals; in the winter, they look like small red tufts (stigmas) protruding from the bud. In chestnut, male and female flowers are borne on the current season's shoots. Male flowers are borne on lateral buds along the lower portion of the shoot; three female flowers are usually located at the base of male catkins.

Pistachios differ from the other nuts discussed in this chapter in that they are dioecious, which means that they have separate male and female trees. Both female and male flowers are borne laterally on 1-year-old wood. Female flowers lack petals. Pistachios tend to bear biennially.

For the development of flowers and fruit in almonds, see the section on stone fruits above16.6.

Vines

Kiwifruit are functionally dioecious. The female flowers appear to be perfect (having both male and female parts), but they produce nonviable pollen. Male plants never produce fruit. Flowers are initiated in late summer, developing from buds in the axils of leaves formed on the current season's shoots (table 16.2 and fig. 16.7).

Figure 16.7

Kiwifruit flowering habit. *Source:* After Hasey et al. 1994, p. 53.

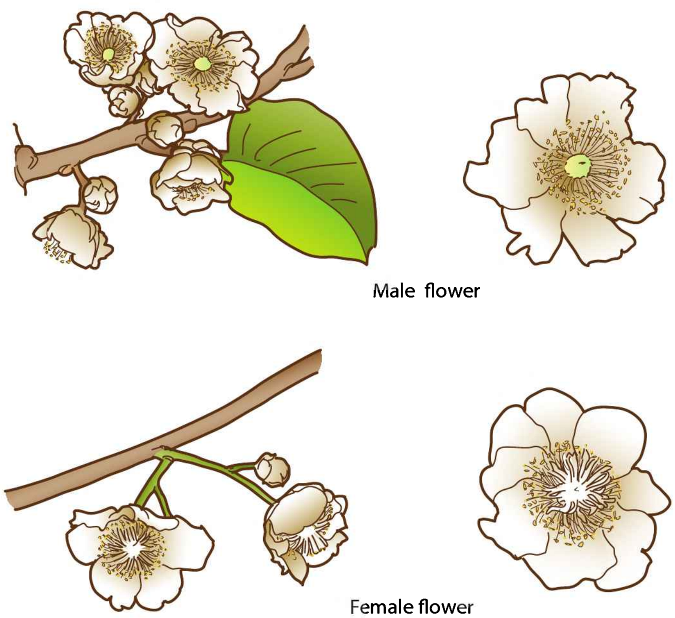


Figure 16.8

Flowering habit of fig. *Source:* After Westwood 1993, p. 222.

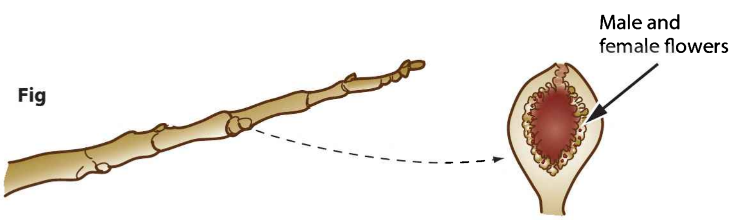
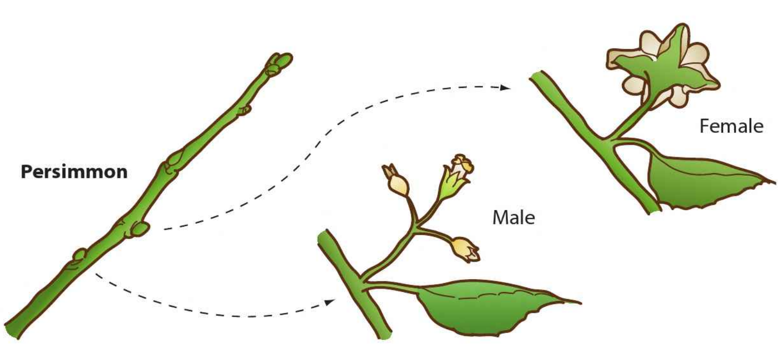


Figure 16.9

Flowering habit of persimmon. *Source:* After Westwood 1999, p. 223.



Other subtropical fruits

Figs often have two crops per season. The flowers of the first crop are initiated on lateral buds in late summer and fall on that season's growth. They overwinter and produce next season's first crop in the spring on 1-year-old wood. These small fruit usually fall off in regions with cold winters. Second-crop flowers are initiated in early summer and bear figs in the fall of the same season (table 16.2 and fig. 16.8) on current season's growth.

Olive flowers are borne laterally in the axils of leaves on last year's shoot growth, and much less often, from dormant buds that are 1 to 2 years old. Olives bear perfect and staminate (male) flowers and in most cases require cross-pollination from a compatible cultivar within about 200 feet.

Persimmons are dioecious. Both male and female flowers are borne at leaf axils on new growth (table 16.2 and fig. 16.9). Persimmon does not require cross-pollination, but in many cases fruit set is better with cross-pollination from male flowers from another cultivar. When cross-pollinated, seed are present; seedless fruit develop when no other cultivars are located within ½ mile.

Pollination

Growing high-quality temperate fruits and nuts with efficient yields in the home garden requires an understanding of pollination. In almond and particularly in multiseeded fruits, such as kiwi, apple, and pear, good pollination, ovary fertilization, and seed development are important to the production of large, attractive fruits. Most nuts (walnut, pistachio, chestnut, pecan, and filbert) and olives are wind pollinated. Many of the temperate fruits are insect pollinated, primarily by bees (fig. 16.10), whose presence is absolutely necessary for good fruit set. Some fruit and nut trees have separate male and female flowers, but their bloom times do not always overlap; others have perfect flowers, but the pollen is not compatible for self-fertilization. Thus, cross-pollination is essential to good fruit set in these trees. It may be necessary to

Figure 16.10

Blossom being pollinated by a honey bee. *Photo:* P. M. Vossen.

have more than one tree of a particular fruit or nut and to plant more than one cultivar to set a good crop. On the other hand, a few deciduous fruit trees are self-fertile, eliminating the need for more than one tree.

For tree fruits with good blooming habits, only a small percentage of the blossoms need pollination to set a full crop of fruit. Nut trees require more extensive pollination because a higher percentage of the flowers become nuts. Under adverse weather conditions or if bloom is sparse, gardeners can help ensure an adequate set by planting pollenizer trees to provide pollen through synchronized bloom. Except for the wind-pollinated species, honey bees or other pollenizing insects are necessary to make sure pollen is transferred between blossoms. Erring on the side of setting too many fruit then hand-thinning excess fruit is preferable to not setting enough fruit. For the wind-pollinated nut crops and olives, some dry weather is needed during the flowering period to get good set. The nut crops are not thinned.

For pollination requirements for most of these crops, see table 16.3. Some general pollination problems are noted below.

Pome and stone fruit trees

Flowers of the pome and stone fruit trees are perfect: they have both male and female organs, but not all cultivars are self-fertile (SF) (see table 16.3). Species that are self-fertile, such as apricot (usually), peach, nectarine, quince, and persimmon (usually), can set a good fruit crop when pollinated by flowers on the same tree, which means that only one tree is needed in the garden. Plum, plumcot, pluot, aprium, and cherry require cross-pollination from a different cultivar within the same species, so at least two trees are needed. Apples normally require cross-pollination; the Gravenstein cultivar even has sterile pollen that will not pollinate any other cultivar. One exception is the Golden Delicious apple, which is a self-fertile cultivar. Partially self-fertile (PSF) species and cultivars set some fruit when pollinated by other flowers on the same tree, but they set better crops if pollinated by a different cultivar, which means that gardeners should consider planting two cultivars in the garden, depending on the yield desired. Olives are considered to be partially self-fertile, but they usually set a better crop when a different cultivar as a pollen source is growing within 200 feet. Self-sterile (SS, but also known as self-infertile or self-incompatible) cultivars require a second cultivar nearby to set fruit because pollen of flowers of the same cultivar does not lead to fertilization and fruit development due to numerous factors. Such self-incompatible cultivars can be cross-pollinated effectively by a second cultivar planted in close proximity. When choosing cultivars for cross-pollination, be sure that their bloom times overlap. A very early bloomer may be almost finished before a late bloomer begins, which could frustrate your efforts for good fruit set in a self-incompatible cultivar.

Nut trees

In walnut, pollination problems do not primarily stem from incompatibility but rather from dichogamy: the time when the stigma is receptive on female flowers does not coincide with the time when the pollen is shed from male flowers on the same tree.

Dichogamy tends to be more pronounced in young trees, but prevailing temperatures, humidity, and overall climate also influence this trait. In general, it is best to plant one walnut cultivar that is protogynous (female flowers are receptive before male flowers shed pollen) and one cultivar that is protandrous (male flowers shed pollen before female flowers are receptive) so that the male bloom of each type overlaps the female bloom of the other type, facilitating effective pollination. Almonds require cross-pollination by another cultivar because they are self-sterile, except for a few cultivars.

Causes of Reduced or Failed Fruit Set

Pollination problems

As discussed above, many cultivated fruit and nut trees are completely or partially self-sterile, have dichogamy, or depend on an adequate supply of bees for pollen transfer from one flower to another. In many cases, the home gardener should review the tree's blooming habits and determine whether they have been adequately met. In some cases this means having two different cultivars flowering at the same time. Rain during bloom reduces pollen transfer of wind-pollinated species because the wet pollen grains stick together and become too heavy for wind dissemination. Strong winds, rain, and cold temperature also greatly reduce or prevent adequate bee activity.

Natural abscission of buds, flowers, and fruit

Even when pollination is successful and the trees are in good health, not all pollinated flowers lead to effective fertilization of ovaries that later become edible fruit. A number of environmental and endogenous factors contribute to reduced fruit set due to abscission (separation) of buds, flowers, and fruit. Large-fruited trees, such as apple, may shed 90% or more of their pollinated flowers and young fruit. However, since a mature apple tree may have more than 100,000 flowers at full bloom, it is a benefit that not all flowers set fruit. Usually, small-fruited species shed a lower percentage of flowers. On many fruit and nut trees, flower buds, flowers, and immature fruit abscise from the trees at distinct times during the year, particularly during June drop (which occurs in May in California). The fruit that remain on the tree are said to have set.

Weather

Flower buds can fail to develop and can drop off the tree when exposed to freezing spring temperatures. The open blossoms of practically all fruit trees may be killed if the temperature drops below 27°F. Even when buds or young fruit appear normal after a frost, if the internal female organs have been killed, the trees bear few fruit. Lack of winter chill (insufficient hours of temperatures below 45°F) may also lead to poor flower development, poor set due to weak prolonged bloom, and in some cases, to flower bud abscission. Cold temperatures above freezing (33°–45°F) during bloom can also reduce fruit set because pollen tube growth is temperature-sensitive. Most flowers are viable for only a few days during which the fertilization process can occur. When the temperature is low, the pollen tube grows too slowly to reach the ovary while the eggs are still viable. Hot, dry winds during bloom can desiccate blossoms and reduce fruit set. Temperatures above 104°F for several days may also lead to abscission of flower and vegetative buds. Some cultivars of cherries develop split ovaries, causing double fruit or spurs, when temperatures are high and water is short during the flower development period the previous summer.

Age and competition

In some plants, flowers develop but do not set during the juvenile phase of plant growth. When competition for nutrients and carbohydrates between the developing fruit and the simultaneous vegetative growth is quite high, flower buds can abscise. Flower abscission also occurs in some cultivars of walnuts when the female

flowers are overpollinated, causing too many pollen tubes to grow down the style.

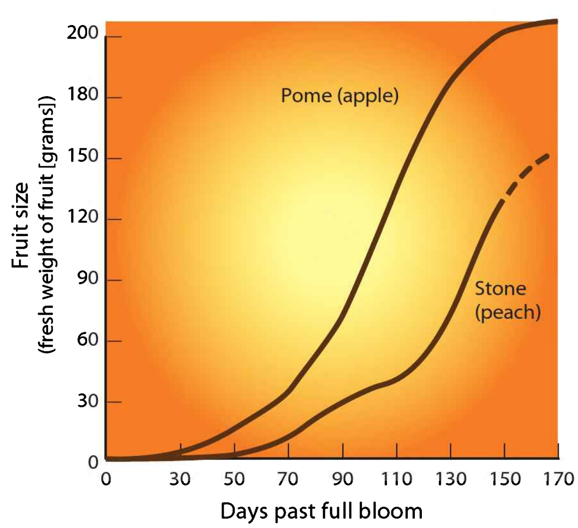
Disease and insect pests
Soilborne diseases, blossom diseases, foliar diseases, and damage caused by insect pests, nematodes, and physiological disorders (see table 16.6) can cause reduced fruit yield because they weaken the tree's health or directly affect the flower or fruit.

Biennial (alternate) bearing
The tendency of some cultivars to bear in alternate years also limits fruit set in the off year. Since the flower buds were actually formed the previous summer (see table 16.2), an especially heavy crop during bud formation may prevent adequate flower buds from forming or cause them to abscise. In some species, heavy thinning or pruning during a year when the tree is producing a large yield can induce a more consistent bearing.

Shade
Adequate sunlight is important for flower differentiation and fruit yield. Fruit trees do best in full sun; do not plant them where shade from a house or other trees will limit light exposure and fruit set during the growing season.

Figure 16.11

Typical sigmoidal fruit growth curves for pome and stone fruits. *Source:* After Westwood 1993, p. 255.



Improper pruning
Severe dormant pruning can remove most of the flower buds that were formed the previous year or lead to excessive vegetative vigor and very poor fruit set.

Factors Affecting Fruit Growth and Size

After pollination and fruit set, the developing fruit are quite small. Many factors influence their growth rate and final size, including cultural practices, fruit physiology, and the environment.

Cultural practices
The home fruit gardener can have a significant effect on the ultimate size of the harvested fruit. The cultural practices that most influence size are thinning and pruning (removing excess fruit on the tree) and irrigation (allowing little or no water stress). Fruit size is affected by the leaf-to-fruit ratio on the tree. Many fruit trees must be thinned early in the season because they set too many fruit in comparison with the number of leaves on the tree. With insufficient leaf area, each fruit would be tiny if allowed to continue growing. Water stress on fruit and nut trees limits cell enlargement of the fruit. It also causes the leaf stomates to close in order to prevent water loss, which reduces gas exchange (carbon dioxide absorption and oxygen release) in the leaves. Less gas exchange results in less photosynthesis and less growth. Thinning and irrigation are discussed in more detail later in this chapter.

Fruit physiology
The number of cells per fruit and their growth potential determine final fruit size. Physiological (internal) and environmental factors influence the duration of cell division and the extent of cell enlargement in a particular fruit type. For plums, peaches, and apples, the period of cell division may last about 1 month. For pears, cell division may last about 2 months. During cell division, cell enlargement also begins. Most fruit growth follows an S-shaped (sigmoidal) curve in which growth is slow initially,

then increases, and ultimately slows again (fig. 16.11).

The reserve food supply that supports growth is located in storage cells of the branches, roots, and trunk. Once leaves reach a certain size, they begin exporting their photosynthates to supply food needs throughout the tree. If fruit set too heavily when reserve and current food supplies are limited, the cell division period in those fruit is cut short, limiting fruit size. Competition between the developing small fruit and vegetative growth is stronger in early-ripening cultivars (late spring to early summer), which must maintain a higher leaf-to-fruit ratio to yield fruit of high quality and adequate size.

Environment

Excessively high temperature, cold spells, water stress, high wind, and improper exposure to sunlight also affect fruit growth and size during the summer. High wind and high temperature increase the transpiration rate in leaves and the respiration rate in fruit, which can reduce fruit size. Heat stress also causes water core in apples, pit-burning in apricots, side-cracking in prunes, and blackening in peaches (see table 16.6).

California Climate Zones for Growing Temperate Tree Fruits and Nuts

University of California scientists divide the state into six main agricultural districts for the production of temperate fruit and nuts (fig. 16.12):

1. San Joaquin Valley
2. Sacramento Valley
3. Central Coast
4. North Coast
5. Sierra Nevada Foothills
6. Southern California

The six regions and their important climatic characteristics with respect to growth of temperate fruit and nut crops are described below.

Zone 1. San Joaquin Valley

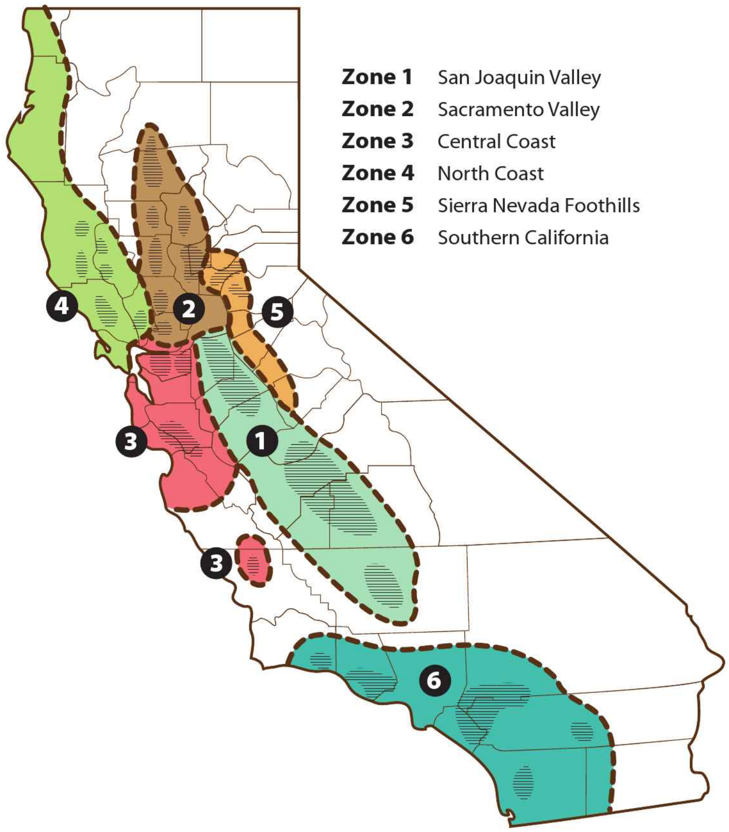
In this region, the maximum temperature during the hottest months of the year (June through August) may exceed 104°F. Average high and low temperatures in Stockton in July are 94°F day and 59°F night; in January they are 56°F day and 38°F at night. More than 80% of the area's precipitation occurs in the winter, with an average 5.7 inches per year at Bakersfield and 14.3 inches at Stockton. Dense fogs lasting a week or more are common in the winter. This region is relatively flat due to alluvial deposits from several California rivers (Stanislaus, Tuolumne, Merced, Fresno, San Joaquin, Kings, Kern, and Kawaeah). Temperate tree fruit and nut crops grown here commercially include almond, apple, cherry, chestnut, fig, kiwifruit, nectarine, olive, peach, pear, pecan, persimmon, pistachio, plum, pomegranate, prune, quince, chestnut, and walnut. The San Joaquin Valley is also the most important area in the state for production of citrus fruit and grapes.

Zone 2. Sacramento Valley

In this region, the winters are cool and moist with fogs that may last a week or more; summers are clear, hot, and dry. Average high and low temperatures in Redding in July are 99°F day and 66°F night; in January they are 55°F day and 36°F night. Annual precipitation in Sacramento averages 17.2 inches, whereas annual precipitation in Redding (in the northern part of the Sacramento Valley) averages 40.9 inches. Like the San Joaquin Valley, this region is relatively flat. It is drained by the south-flowing Sacramento River, which is joined by several rivers from the Sierra Nevada. The main temperate fruit and nut crops grown commercially in the Sacramento Valley are almond, apple, apricot, kiwifruit, olive, peach, pear, pecan, pistachio, plum, prune, chestnut, and English and black walnut. Some wine grapes and cold-hardy citrus are also grown.

Figure 16.12

Major temperate fruit and nut producing zones in California. *Source:* After Ogawa and English 1991, p. 3.



Zone 3. Central Coast

The climate in the Central Coast is influenced by the Pacific Ocean. Salinas, which is about 10 miles from the ocean in Monterey County, has average high and low temperatures in July of 66°F day and 52°F night; in January they are 58°F day and 44°F night. The warmest month is September, due to less fog. Annual precipitation in Salinas averages 13.7 inches. The region generally has a mild climate, with cool summers on the coast, where fog is common, and warm summers in the interior (but not as warm as the Central Valley). Inland areas out of the fog influence are considerably warmer in summer and colder in winter. Although frosts are infrequent in the winter near San Francisco, low-lying areas in the interior of this region can have temperatures below freezing. Winter protection and site selection can be critical factors in some locations. The main temperate fruit and nut crops that have been grown commercially in this area are apple, apricot, cherry, prune, olive, and walnut. It is also a major wine grape and berry production area.

Zone 4. North Coast

The North Coast is the wettest region of the state. Annual precipitation averages 25 to 80 inches, which can cause disease in the spring during bloom and root rot. The North Coast has a rugged terrain, with coastal plains and a few small valleys. Average high and low temperatures in Santa Rosa in July are 82°F day and 52°F night; in January they are 59°F day and 39°F night. The main temperate tree fruit and nut crops grown commercially in this region are apple, pear, prune, olive, chestnut, and walnut. It is also the primary premium wine grape region of the state.

Zone 5. Sierra Nevada Foothills

This region is a narrow, hilly area on the east side of the Central Valley. Although commercial production has declined in this region due to competition from higher-yielding orchards in the Central Valley, home gardeners can grow many temperate fruit and nut crops in this region at elevations ranging from 500 to 3,000 feet. In many locations, soil is shallow and rocky, but a few narrow valleys have alluvial, valley bottom, and terrace soil. Annual precipitation ranges from 20 to 40 inches. Spring frosts, especially at the higher altitudes, can reduce production. Average high and low temperatures in Placerville are 93°F during the day and 61°F at night; in January they are 56°F day and 35°F night. The main temperate fruit and nut crops that have been grown commercially in this region are apple, cherry, peach, pear, pistachio, quince, persimmon, plum, prune, olive, chestnut, and walnut.

Zone 6. Southern California

The southern California coast is influenced by the Pacific Ocean and has a mild climate due to the marine air. Summers are moderate in temperature, and coastal fog is common. Hot, dry winds known as Santa Anas can be damaging on the coast and in the inland areas of southern California. The interior is more subject to hot, dry desert air than the coast and is considerably warmer. Higher-elevation areas in southern California have a climate more similar to the mountain foothills. Annual rainfall along the coast can be as high as 16 inches in Santa Barbara and as low as 9 inches in San Diego. Average high and low temperatures in Los Angeles in July are 83°F day and 64°F night; in January they are 68°F day and 48°F night.

Droughts are not uncommon in southern California, and all crops require irrigation. The main temperate fruit and nut crops grown commercially in this region are apple, macadamia, olive, peach, persimmon, and English walnut. Since winters along the southern California coast and interior are usually mild and often frost-free, temperate tree fruit cultivars with low winter chill requirements are usually chosen because the low latitudes in this region receive a more limited number of total hours between 45°F (night) and 60°F (day).

See the next section, "Cultivars," for information on apple, pear, peach, nectarine, apricot, Japanese and hybrid plums, and kiwifruit reported to have low winter chilling requirements that can be grown successfully in this region by home gardeners.

Cultivars

The climate zone (see fig. 16.12) determines which cultivars of temperate tree fruit and nut crops perform best in the home garden, when fruits and nuts are harvested, and which pest and disease problems are more common.

This section describes selected cultivars of the major and minor temperate fruit and nut crops that are suitable for home gardeners in California. The tables could easily be doubled or tripled in size if all heirloom cultivars and newer cultivars available at nurseries or through mail order were included. Grapes, berries, and other tree crops are discussed in other chapters in this book; refer to those chapters for cultivar information.

Certain cultivars are superb eaten fresh; other cultivars tend to be used more often for cooking, canning, and freezing. Experts do not always agree about which cultivars are best suited for various uses because individual tastes differ. Almost all cultivars have excellent quality fruit if harvested at the perfect maturity and eaten right away. The comments in this section regarding these issues are offered as points of interest only, not as official advice endorsed by the University of California.

Pome Fruits

Apple

Apples (*Malus domestica*) are adapted to many areas of California. A cool climate is needed for coloration in most red cultivars. Winter chilling requirements for most cultivars are 500 to 1,000 hours below 45°F; low-chill cultivars need about 400 to 600 hours below 45°F. Foggy days and dews can cause heavy cosmetic russetting on fruit. There are hundreds of apple cultivars (fig. 16.13), and some cultivars have several strains, each with its own characteristics. Spur-type (short shoot growth and abundant spur production) cultivars do poorly on dwarfing rootstocks; they are best grown on seedling rootstocks. Several rootstocks are available that impart dwarfing and pest resistance. Apple cultivars exhibit considerable genetic diversity. Some require as few as 70 days to mature; others take 180 days or more. Some cultivars are very cold-hardy; others are tender. Apples require cross-pollination from another cultivar that blooms at the same time and produces abundant, viable pollen. Many cultivars are self-unfruitful and have sterile pollen; others are partially self-fruitful (not all of their pollen is viable); a few are self-fruitful. It is best to plant apple trees from January to March.

Figure 16.13

Numerous apple cultivars on display. *Photo:* P. M. Vossen.

APPLE ROOTSTOCKS

Apple rootstocks	Comments
M7a	Semidwarf rootstock. Usually produces a tree about 60% the size of the same tree on seedling rootstock. Performs well in irrigated replant situations but tends to sucker. Spacing is same as M106.
M9	Dwarfing rootstock. Usually produces a very small tree, less than 30% the size of the same tree on seedling rootstock. Commercially, the most frequently planted rootstock worldwide. However, a poor performer if not adequately managed. Poorly anchored, it has a brittle root system. Must be trellised.
M26	Semidwarf to dwarfing rootstock. Usually produces a tree 30 to 50% the size of the same tree on seedling rootstock. Performs poorly in most California locations. May need a support system and is highly susceptible to fire blight disease.
M106	Semidwarf rootstock. Usually produces a tree about 65 to 75% the size of the same tree on seedling rootstock. Provides good anchorage. Imparts early bearing to fruit and is easily propagated. Reportedly resistant to woolly apple aphid. Requires irrigation. Tree spacing ranges from 10 by 18 ft to 6 by 12 ft.
M111	Semidwarf rootstock. Usually produces a tree 80% the size of the same tree on seedling rootstock. Tolerates many soil conditions. Reportedly resistant to woolly apple aphid. Imparts earlier bearing than seedling but not as early as more-dwarfing stocks. Requires irrigation. Vigor is difficult to control.
Mark	Dwarfing rootstock. Relatively new. Similar in size to M9. Very precocious. Poor performer in all apple-growing regions of California.
Seedling	Used for nonirrigated sites, low-vigor sites, and weaker cultivars. Very vigorous; produces large, full-sized trees that come into bearing late (7–10 years). Susceptible to woolly apple aphid. Trees can fill a 30 by 30 ft space and grow 20 ft tall.

STANDARD APPLE SCION CULTIVARS

		Harvest*					
Apple scions	Comments	San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Fuji	Round to flat apple with very sweet yellow-orange flesh. Skin is red if given enough sunlight and cool temperatures. One of the best sweet eating apples. Stores well.	Oct–Nov	late Oct-Nov	Nov	Nov	late Oct–Nov	NA†
Gala	Small to medium sized, conic red apple with excellent flavor and keeping qualities. The best cultivar for the early season.	late Jun	late Jun	early Jul	late Jul	early Jul	late Jun

STANDARD APPLE SCION CULTIVARS cont.

Apple scions	Comments	Harvest*					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Gravenstein	Medium-large fruit with short, fat stem. Skin is greenish yellow overlaid with red stripes. Excellent flavor when fully ripe. Crisp, subacid, and aromatic. A good sauce and pie apple. Stores and ships poorly. High percentage of windfalls. Sterile pollen.	late Jun	late Jun	early Jul	late Jul	early Jul	NA
Golden Delicious	Conic apple with a long stem, yellow to green skin, yellow flesh, and russet dots. Sweet, juicy, fine textured. Number one on the California North Coast for fresh eating quality and processing. Stores well but susceptible to bitter pit, bruising, russeting. Erratic in self-fruitfulness.	late Aug	late Aug	Sep	late Aug–Sep	Sep	NA
Granny Smith	Round, green to yellow–skinned apple that is quite firm. Keeps very well. Crisp flesh. If harvested early, it is green and tart. Late-harvested fruit are yellow and sweet.	Oct–Nov	late Oct–Nov	Nov	Nov	late Oct–Nov	NA
Jonathan	Round, red apple with pure white flesh. Crisp, juicy, and slightly subacid. Excellent for eating fresh, sauce, and juice. Highly susceptible to mildew, fire blight, and Jonathan spot.	Aug	Aug	late Aug–Sep	mid-Aug –Sep	mid-Aug	NA
Red Delicious	Conic apple with tapered base and five distinct lobes. Skin color varies from solid red to a mixture of red and green stripes. Crisp, sweet, mild-flavored yellow flesh. Many strains. Best used fresh. Stores well.	late Aug	late Aug	Sep	late Aug–Sep	Sep	NA
Rome Beauty	Round fruit with a deep cavity, no lobes, and little russet. Several strains, including the old standard and several new strains with solid red skin, such as Taylor and Law. Stores moderately well. Tree leafs out late, flowers late, and produces flowers and fruit on long spur growth that requires modification in pruning. Good for baking.	Oct–Nov	late Oct–Nov	Nov	Nov	late Oct–Nov	NA

OTHER APPLE CULTIVARS

Other apple cultivars	Comments	
spur type	Strains (mutations) of the original cultivars that have shorter internodes and are naturally dwarfing. Best on seedling rootstock.	Golden Delicious Spur (Nugget Spur, Goldspur, Yelo Spur, and Starkspur), Red Delicious Spur (Silverspur, Crimson Spur, Skyspur), Bisbee Spur, Spured Royal, Oregon Spur, Wellspur, Scarletspur, Cascade Spur, Starkspur, Spur McIntosh, Granny Smith Spur, Greenspur, Granspur, Rome Beauty Spur, Law Spur, Spuree, Winesap Spur, Arkansas Black Spur.
low chill	These cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements (< 300 hours).	Anna, Beverly Hills, Dorsett Golden, Einshemer, Gordon, Tropical Beauty.
antique	These cultivars do well in much of California if there is adequate chilling and summer heat is not too intense. They are hard to find because they lack commercial value. Many have excellent flavor and perform well in home gardens.	Arkansas Black, Baldwin, Black Twig, Cox's Orange Pippin, E. Spitzenburg, McIntosh, Newtown Pippin, Northern Spy, Red Golden, Rhode Island Greening, Sierra Beauty, Smith Cider, Staymen Winesap, Wagner, Winesap, Winter Banana.
early summer	These cultivars do not have the high-quality characteristics of standard cultivars but ripen early when no other fresh apples are available. They are good for eating fresh and cooking.	Akane: Similar to Jonathan but earlier, good solid red color, white flesh, good for eating fresh and juice. Jerseymac: Large, good red color, excellent flavor, firmer than McIntosh, stores 4 to 8 weeks. Jonamac: Similar to McIntosh but has better color, firmness, and storage life. Paulared: High-quality, white flesh, stores fairly well, tree requires thinning. Vista Bell: Terminal bearing habit, white-fleshed fruit, stores well.

OTHER APPLE CULTIVARS cont.

Other apple cultivars	Comments	
disease resistant	Several scab-resistant apple cultivars have been developed in breeding programs for the eastern United States, where this disease is quite severe due to summer humidity and rain. Some have received limited testing under California growing conditions. In growing districts with extended spring rains, organic growers should experiment with these cultivars to see how they perform in their orchards.	Enterprise: A large-fruited, late-maturing, dense, crisp cultivar that has good keeping qualities. The skin is dark red over a yellow-green background. One of the best of the scab-resistant cultivars. Florina: A promising scab-resistant selection from France, with large, round-oblong, purple-red fruit; ripens late and has a mixed sweet tart flavor. Freedom: A late-season cultivar with large fruit and mild flavor; not completely immune to scab. Goldrush: A scab-immune selection with Golden Delicious parentage; late maturing, large, firm textured, and tart with an excellent flavor; stores well. Jonafree: A midseason apple that compares with Jonathan, with soft flesh and uneven coloring. Liberty: One of the best-quality apples of the disease-resistant cultivars; is very productive and requires heavy early thinning to achieve good size; ripens in midseason, has an attractive red color with some striping, and a good, sweet flavor. Prima: An early-season, uneven-ripening, moderate-quality cultivar. Priscilla: A late-season cultivar with small fruit, soft flesh, and mild flavor. Pristine: Moderate to large, tart, yellow apple immune to scab and resistant to fire blight and mildew. Red Free: Matures in early July, heat-sensitive, small fruited; susceptible to water core, sunburn, and russet. Williams Pride: Early maturing, scab immune; also resistant to fire blight and mildew; medium to large fruit with a round-oblique shape; attractive red striped color on a green-yellow background.

Pear

Of all the deciduous fruit tree species, pears (*Pyrus* spp.) are the most tolerant of wet soil conditions, but they perform best on deep, well-drained sites. Pears are the most pest-ridden of all fruit trees, and they require the most sprays to produce quality fruit. Without dwarfing rootstock or summer pruning, pear trees get very large, requiring a spacing of 18 by 18 feet. Pear trees have a tendency to grow very upright and must be trained to develop a spreading growth habit. Most pear cultivars are self-sterile and require cross-pollination by another cultivar to get a good crop set. One exception is in the Sacramento River Delta region, where Bartlett is self-fruitful, setting crops of parthenocarpic fruits. Fire blight (a bacterial disease) is a serious problem in pears. Bartlett, which makes up 75% of the world's production and acreage, has a chilling requirement of about 800 hours (fig. 16.14). Days from full bloom to harvest range from about 115 to 165 for European and Asian pears.

Figure 16.14

Bartlett pears. *Photo:* P. M. Vossen.

PEAR ROOTSTOCKS

Pear rootstocks	Comments
Betulaefolia	Best rootstock for most Asian pears. An Asian seedling. The most vigorous, producing the largest tree on the poorest site. Best tolerance of wet and drought conditions. Resistant to decline, blight, root aphid, and root rot. Poor stock for D'Anjou.
Calleryana	Moderately vigorous rootstock. Resistant to wet feet (Phytophthora), fire blight, root aphid, and most nematodes. Not the best stock for Asian cultivars. Produces a tree a bit larger than French Seedling.
French Seedling	Seed from Bartlett or Winter Nellis are used for this rootstock, which withstands both wet feet and dry conditions. Resistant to oak root fungus but is very susceptible to fire blight. Good for general use.

PEAR ROOTSTOCKS cont.

Pear rootstocks	Comments
Old Home × Farmingdale	A *Pyrus communis* rootstock propagated by cuttings or layering. Somewhat dwarfing. Compatible with most cultivars. Resistant to fire blight.
Quince (several strains)	Semidwarfing rootstock. Resistant to decline, root aphid, root rot, and most nematodes. Trees are 50% of standard size and are very productive. Compatible with Anjou, Comice, Flemish Beauty, and Swiss Bartlett. Graft-incompatible with Bartlett, Bosc, Clapp, and Seckel; requires an interstem of Old Home. On poor sites trees tend to be runty. Fruit quality is lower than on other stocks. Several different species are used for pear rootstocks, but they vary only slightly in their tolerance to wet feet and size control. Quince is the only dwarfing stock available, and it is incompatible with some cultivars.

EUROPEAN PEAR SCION CULTIVARS (*PYRUS COMMUNIS* L.)

Most of these cultivars have the traditional pear shape and are harvested green when they begin to drop off the tree. They are then stored at 33° to 45°F for several weeks. As the fruit is brought up to room temperature, it softens and turns buttery. If allowed to ripen on the tree, "stone" cells develop within the flesh that make the fruit gritty.

		Harvest					
Pear scions	Comments	San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Bartlett	The best-quality pear fruit. Bell shaped with white flesh and excellent flavor. Tree is susceptible to fire blight. Fruit keep relatively well, up to 2 months after maturing in August. Sensation is a red Bartlett.	Aug	Aug	late Aug	late Aug	Aug	NA
Bosc	Midseason cultivar that bears heavy crops regularly. Fruit are long and tapering, with a long neck and stem. Skin is golden russet brown.	Oct	Oct	Oct	Oct	Oct	NA
Comice	Inconsistent bearer. Excellent fruit, green with red blush. Delicate skin, chubby shape. Very vigorous tree, does best on Quince rootstock. Late maturing.	Oct	Oct	Oct	Oct	Oct	NA
D'Anjou	Good winter pear with excellent keeping qualities. A large, vigorous tree. Egg-shaped fruit with a small shoulder. Light green to yellow-green color with white flesh. French origin. There is a red strain called Red Anjou.	Sep	Sep	Sep	Sep	Sep	NA
Seckel	The small fruit are reddish green, with very dense, sweet, flavorful flesh. Excellent quality for the home orchard. Resistant to fire blight and pear scab.	Sep	Sep	late Sep	late Sep	Sep	NA
Winter Nellis	Medium-small, almost round fruit with light russeting over a green skin. Resistant to blight. Large tree. Regular producer, but late.	Oct	Oct	Oct	Oct	Oct	NA
low chill	These pear cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements (< 300 hours).	Baldwin, Carnes, Fan Stil, Florida Home, Garber, Hengsan, Hood, Kieffer, Orient, Pineapple, Seleta, Spadona.					

ASIAN PEAR SCION CULTIVARS (*PYRUS SEROTINA* L.)

Asian pears are round fruit that remain very firm, crisp, and juicy when eaten ripe. They are also known as salad pears or pear apples. The best rootstock for these cultivars is Betulaefolia. Generally require cross-pollination. Fruit must be heavily thinned in May or June to size properly; the largest fruit are produced if flowers are thinned during bloom. Harvest by taste and pick exposed fruit first. Unlike European pears, Asian pears ripen on the tree.

Asian pear scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Chojuro	Greenish brown to brown russet skin. Coarse, tasty flesh.	late Jul	late Jul	Aug	early Aug	early Aug	Aug
Hosui	Brown skin, juicy white flesh with a sweet aromatic flavor.	late Aug	late Aug	Sep	early Sep	late Sep	early Sep
Kikusui	Yellow-green skin. White flesh, excellent flavor. Fruit drop from tree when ripe.	Aug	Aug	late Aug	mid-Sep	late Aug	NA
Niiataka	Very large, juicy fruit with an aromatic flavor.	late Sep	late Sep	mid-Oct	Oct	Oct	late Sep
Nijisseiki	Also known as Twentieth Century. Excellent quality. Very popular cultivar, yellow-green skin.	Aug	Aug	late Aug	mid-Sep	late Aug	NA
Shinko	Brown russet skin; firm, crisp flesh; very aromatic flavor.	late Sep	late Sep	mid-Oct	Oct	Oct	late Sep
Shinseiki	Amber yellow skin. White flesh is crisp but softens rapidly; less flavor than other cultivars.	Aug	Aug	late Aug	mid-Sep	late Aug	NA
Tsu Li	Blooms early. Use Ya Li (below) as pollenizer. Chinese type (pear shape). Light green color, crisp, tasty flesh.	late Sep	late Sep	mid-Oct	Oct	Oct	late Sep
Ya Li	Blooms early. Use Tsu Li (above) as pollenizer. Chinese type (pear shape). Light, shiny yellow color, crisp, tasty flesh.	late Sep	late Sep	mid-Oct	Oct	Oct	late Sep

Pomegranate

Pomegranates (*Punica granatum L.)* (fig. 16.15) are exotic fruit that grow on a small tree or shrub 15 to 20 feet tall that has shiny foliage and a long flowering season. The tree is very long-lived. It is sensitive to frost in fall and spring and does not mature well in cool climates. The tree tolerates wet, heavy soil but performs better in deep, well-drained loams. Fruit crack with first fall rains. Pomegranates are propagated from cuttings and require only a short chilling period. They are resistant to oak root fungus *(Armillaria mellea)* and not attacked by codling moth or twig borers. Unharvested ripe fruit attract ants and fruit flies.

Figure 16.15

Small pomegranate fruit and flowers. *Photo:* P. M. Vossen.

POMEGRANATE CULTIVARS

Pomegranates	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Ambrosia	Huge fruit, pale pink skin; similar to Wonderful.	Sep	Sep	Oct	Oct	Sep	Sep
Eversweet	Very sweet, almost seedless fruit. Red skin, clear juice. Good for coastal areas.	Aug	early Sep	Oct	Oct	early Sep	early Sep
Granada	Deep crimson fruit color. Matures early but needs heat.	Aug	early Sep	Oct	Oct	early Sep	early Sep
Ruby Red	Matures late (with Wonderful) but not as sweet or colorful as Wonderful. All fruit matures at once.	Sep	Sep	Oct	Oct	Sep	Sep
Wonderful	Large, deep red fruit. Large, juicy, red kernels. Small seed. Matures late. Juice is made into grenadine syrup.	Sep	Sep	Oct	Oct	Sep	Sep

Quince

Quince (*Cydonia oblonga* Mill.) fruit grow on a small tree or shrub (8–12 ft tall) with twisted, bumpy branches (fig. 16.16). Grown as a flowering ornamental or for fruit processing. Adapted to many climates. Tolerates wet feet better than most other deciduous fruit trees. Quince trees bloom late, which means that they avoid spring frosts. Quinces have many of the same pest problems as apple and pear. Cultivars are self-fruitful; used as a dwarfing rootstock for pear.

Figure 16.16

Quince fruit and leaves. *Photo:* P. M. Vossen.

QUINCE CULTIVARS

		Harvest					
Quinces	**Comments**	**San Joaquin Valley**	**Sacramento Valley**	**Central Coast**	**North Coast**	**Sierra Nevada Foothills**	**Southern California**
Champion	Green-yellow flesh. Pear-shaped fruit.	early Oct	early Oct	Oct	Oct	Oct	early Oct
Orange	Orange-yellow flesh. Golden skin. Rich flavor. Low-chill cultivar.	early Sep	early Sep	Sep	Sep	Sep	early Sep
Pineapple	The preferred cultivar. Pineapple flavor. White flesh. Golden skin. Low-chill fruit.	early Oct	early Oct	Oct	Oct	Oct	early Oct
Smyrna	Large fruit with brown pubescence. Light, tender flesh. Yellow skin. Low-chill fruit.	early Oct	early Oct	Oct	Oct	Oct	early Oct
Van Deman	Pale yellow, coarse flesh. Orange skin turns red when cooked.	early Sep	early Sep	Sep	Sep	Sep	early Sep

Stone Fruits

Almond (*Prunus dulcis*)

Almonds are stone fruits but are consumed as nuts. Please see “Nut Crops,” below.

Apricot

Apricots (*Prunus armeniaca* L.) (fig. 16.17) bloom in February and early March. In some areas of the state, such as the North Coast counties, this usually coincides with cold and rain; consistent crops are unlikely in these areas. Apricots perform best in climates with dry spring weather. They are susceptible to late-spring frosts. Bacterial canker is a common disease of young trees in California. Plant trees at a spacing of about 10 to 20 feet. Apricots are mostly self-fruitful and ripen in late June to July (100–120 days from full bloom). The hot weather in areas of the Central Valley often cause the fruit to “pit burn” (soften and turn brown around the pit), which lowers quality.

Figure 16.17

Apricots. *Photo:* P. M. Vossen.

APRICOT ROOTSTOCKS

Apricot rootstocks	Comments
Citation	One of the best rootstocks for apricots. Slightly dwarfing. Less susceptible to bacterial canker; tolerant of wet feet.
Lovell Peach	Imparts some resistance to bacterial canker. Susceptible to oak root fungus. Not as tolerant of wet soil as other apricot rootstocks.
Marianna 2624	Somewhat resistant to oak root fungus. Tolerates wet feet much better than apricot or peach rootstocks. Space trees 20 ft apart.
Prunus besseyi	Semidwarfing rootstock. Short-lived. Suckers profusely. Produces inferior fruit in the scion cultivar.

APRICOT SCION CULTIVARS

Apricot scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Autumn Royal	Blenheim sport (mutation). Ripens in late summer to fall.	Jun	Jun	early Jul	late Jun	late Jun	Jun
Moorpark	Excellent flavor, ripens unevenly, highly colored.	Jun	Jun	early Jul	late Jun	late Jun	Jun
Royal (Blenheim)	Large, very flavorful, used for eating fresh and drying.	Jun	Jun	early Jul	late Jun	late Jun	Jun
Tilton	Large fruit, heavy producer. Mild flavor. Used for canning.	early Jul	Jul	late Jul	late Jul	Jul	Jul
low chill	These apricot cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements (< 300 hours).	Early Gold, Goldkist, Newcastle					
newer cultivars	These cultivars are newer and should be evaluated for your climate zone and site before being selected.	Castlebright, Earl Golden, Golden Amber, Goldrich, Improved Flaming Gold, King, Pomo, Riland, Rosa, Royalty, Sun Glo					

Cherry

Two types of cherries *(Prunus avium L, Prunus cerasus L.)* can be planted: sweet, for fresh eating (fig. 16.18), and sour, for pies and preserves. Generally, cherries are the most difficult fruit trees to keep alive. They do not tolerate wet feet and are very susceptible to brown rot, bacterial canker, cytospora canker, root and crown rots, and several viruses. Trees must be planted 14 to 20 feet apart in well-drained soil and up on a small mound or berm. Sweet cherries require cross-pollination (many cultivars are self-sterile and intrasterile, as noted below). Sour cherries are self-fertile and do not require pollenizers. Both types require less than 100 days to mature.

Figure 16.18

Sweet cherries. *Photo:* P. M. Vossen.

CHERRY ROOTSTOCKS

Cherry rootstocks	Comments
Colt	Somewhat dwarfing rootstock. The leading rootstock in California.
Giesla Series	These dwarfing rootstocks are relatively new and in most cases produce smaller trees (8–10 ft). They also tend to impart early bearing. The smaller trees are easier to cover with netting to discourage birds. Most lose production potential after 8–10 years.
Mahaleb	Very susceptible to root and crown rots. Some resistance to buckskin virus, bacterial canker, and root lesion nematode.
Mazzard	Good rootstock for cherries in coastal California. Produces a large, vigorous tree that is delayed in coming into bearing. Less susceptible to root rots and gophers than Mahaleb but more susceptible to bacterial canker than Mahaleb.

CHERRY ROOTSTOCKS

Cherry rootstocks	Comments
Stockton Morello	Somewhat dwarfing rootstock. Not readily available. Makes an overgrowth at the bud union. Propagated from a cutting. As tolerant as Mazzard to wet feet. Somewhat resistant to gophers; less susceptible to bacterial canker. Generally a very good rootstock.

SWEET CHERRY SCION CULTIVARS

Sweet cherry scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Bing	Industry standard. Deep mahogany red fruit. Produces very heavily. Very susceptible to bacterial canker. Pollenized by Van, Black Tartarian, or Sam. Bing, Lambert, and Royal-Ann will not pollinate each other (they are intrasterile).	Jun	Jun	late Jun	late Jun	Jun	NA
Black Tartarian	Small, black fruit. A good pollenizer for Bing and most other cultivars.	Jun	Jun	late Jun	late Jun	Jun	NA
Brooks	A large, dark red fruit with good flavor. Produces few doubles even in hot climates.	mid-Jun	mid-Jun	Jun	Jun	Jun	NA
Early Burlat	Moderate-sized fruit. Ripens 2 weeks before Bing. Soft flesh. Pollenized by Bing and B. Tartarian.	early Jun	early Jun	Jun	Jun	Jun	NA
Early Ruby	Early season. Large, dark red fruit. Prolific. Fruit hold on tree.	early Jun	early Jun	Jun	Jun	Jun	NA
Lambert	Dark, large, firm fruit. Pollenized by Van. Late season. Lambert, Bing, and Royal-Ann do not pollinate each other.	late Jun	late Jun	Jul	Jul	Jul	NA
Rainier	Yellow-red blush. Large, crack-resistant fruit.	Jun	Jun	late Jun	late Jun	Jun	NA
Royal-Ann	Yellow fruit with a red blush. Pollenized by Van. Late season. Royal-Ann, Lambert, and Bing will not pollinate each other.	early Jun	early Jun	Jun	Jun	Jun	NA
Stella	Dark-fleshed fruit. Matures just after Bing. Self-fruitful.	late Jun	late Jun	Jul	Jul	Jul	NA
Van	Large, dark fruit. Pollenized by Bing or Lambert.	Jun	Jun	late Jun	late Jun	Jun	NA
low chill	None available.						

SOUR CHERRY SCION CULTIVARS

Sour cherry scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Early Richmond	Very early in season. Bright red fruit.	early Jun	early Jun	Jun	Jun	Jun	NA
Meteor	Semidwarf.	early Jun	early Jun	Jun	Jun	Jun	NA
Montmorency	The leading sour cultivar. Medium-sized, dark red fruit.	early Jun	early Jun	Jun	Jun	Jun	NA
North Star	Semidwarf. Self-fruitful.	early Jun	early Jun	Jun	Jun	Jun	NA
low chill	None available.						

Nectarine

Nectarines (*Prunus persica*) are fuzzless peaches (fig. 16.19). They do well in most of California if given the proper growing conditions. Nectarines require very well drained soil, abundant nitrogen fertility, plenty of summer water, fruit thinning, and sprays to prevent peach leaf curl and brown rot. New cultivar developments have greatly improved this fruit as a tree for backyard and commercial use. Trees can bear the second year. Nectarines (like peaches) are self-fruitful and do not require a pollenizer tree. Tree spacing should be about 8 to 12 feet apart.

Figure 16.19

Nectarines, with smooth skin. *Photo:* P. M. Vossen.

NECTARINE ROOTSTOCKS

Nectarine rootstocks	Comments
Citation	A new peach-plum hybrid that provides some dwarfing to most cultivars. Tolerates wet winter conditions. Produces trees that are smaller in trunk diameter without any height reduction in some cultivars.
Lovell Peach	The best choice for coastal California. A seedling that tolerates wet winter soil better than any other peach rootstock. Produces a full-sized tree that is managed easily. Plant 8-14 ft apart.
Nemaguard Peach	The best choice for the Central Valley. A nematode-resistant rootstock best adapted to sandy, dry sites that don't get too wet.
Prunus besseyi	Semidwarfing rootstock. Suckers profusely. Produces inferior fruit on the scion cultivar. Has not performed well. Somewhat incompatible with all nectarine cultivars.

NECTARINE SCION CULTIVARS

Nectarine scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Arctic Glo	Small, fantastic flavor. White flesh. Early.	mid Ju-	mid-Jun	early Jul	Jun	Jun	NA
Fantasia	Large, brightly-colored yellow freestone. Late.	late Jul	Aug	late Aug	mid-Aug	Aug	Aug
Flamekist	Excellent quality. Large, firm, yellow, clingstone.	late Aug	early Sep	Sep	Sep	Sep	Sep
Flavortop	Large, excellent flavor. Yellow, freestone. Midseason.	mid-Jul	late Jul	Aug	Aug	Aug	late Jul
Goldmine	Large, great flavor. White flesh. Freestone.	Aug	late Aug	Sep	Sep	Sep	Sep
Heavenly White	Large, excellent flavor. White flesh.	late Jul	late Jul	mid-Aug	early Aug	early Aug	NA
May Grand	Large, yellow fruited, freestone. Early.	early Jun	mid-Jun	late Jun	late Jun	Jun	Jun
Panamint	Medium-sized fruit. Red skin, golden flesh. Freestone, low-chill cultivar.	late Jul	early Aug	Aug	Aug	Aug	Aug
Red Gold	Large, excellent flavor. Stores well. Late.	late Aug	early Sep	Sep	Sep	Sep	Sep
Rose	Old favorite white freestone with excellent flavor and low-chilling requirement.	mid-Jul	late Jul	Aug	Aug	Aug	late Jul
September Red	Large, yellow. Very late.	late Aug	early Sep	Sep	Sep	Sep	Sep
Snow Queen	Early-season white freestone, juicy and tasty.	late Jun	Jul	late Jul	late Jul	late Jul	Jul
Summer Grand	One of the best. Large, yellow, freestone.	mid-Jul	late Jul	Aug	Aug	Aug	late Jul
low chill	These nectarine cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements.	Desert Dawn, Desert Delight, Panamint, Pioneer, Rose, Silver Lode					

Peach

Peaches (*Prunus persica*) are very popular fruit trees that can be grown successfully in many parts of California (fig. 16.20). They require adequate summer watering, deep and well-drained soil, high nitrogen fertility, fruit thinning, and sprays to prevent peach leaf curl and brown rot. Peach trees are short-lived (15–20 years). Peaches (like nectarines) are self-fruitful (self-compatible), which means that they do not require a pollenizer tree. Plant trees 12 by 16 feet to 18 by 18 feet apart.

Figure 16.20

Peaches, with fuzzy skin. *Photo:* P. M. Vossen.

PEACH ROOTSTOCKS

Peach rootstocks	Comments
Citation	A new peach-plum hybrid that provides some dwarfing to most cultivars. Tolerates wet winter conditions. Produces trees that are smaller in diameter without any height reduction in some cultivars.
Lovell Peach	The best choice for coastal California. A seedling that tolerates wet winter soil better than any other peach rootstock, but still requires good drainage. Produces a full-sized, small tree that is managed easily. Plant 8–14 ft apart.
Nemaguard Peach	The best choice for the Central Valley. A nematode-resistant rootstock best adapted to sandy, dry sites that don't get too wet. Full-sized tree.
Prunus besseyi	Semidwarfing rootstock. Suckers profusely. Produces inferior fruit on the scion cultivar. Has not performed well. Somewhat incompatible with all peach cultivars.

PEACH SCION CULTIVARS

Thousands of peach cultivars have been developed worldwide. Some perform better in warmer areas; others have better fruit quality when grown in cooler climates along the coast of California. Three listed below (La Feliciana, Loring, and Veteran) are somewhat more disease resistant than the others.

		Harvest					
Peach scions	Comments	San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Autumn Gold	Medium-large fruit. Yellow flesh. Keeps well.	Sep	Sep	Oct	Oct	Oct	NA
Babcock	Medium sized. White flesh. Freestone, low-chill cultivar.	late Jun	Jul	Jul	late Jul	Jul	late Jun
Earligrande	Excellent flavor. Yellow-red blush. Semifreestone, low-chill cultivar.	May	late May	Jun	Jun	Jun	May
Fairtime	Large fruit. Yellow, firm flesh. Excellent flavor.	Sep	Sep	Oct	Oct	Oct	NA
Fay Elberta	Large fruit. Yellow flesh. Freestone.	late Jul	late Jul	mid-Aug	early Aug	Aug	NA
Forty-Niner	Large fruit. Yellow flesh. Freestone.	late Jul	late Jul	mid-Aug	early Aug	Aug	NA
Indian Blood	Cling. Red skin and flesh. Tart. Prolific.	late Aug	late Aug	Sep	Sep	Sep	NA
La Feliciana	Medium sized. Firm, red. Excellent flavor.	mid-Jul	late Jul	Aug	Aug	late Jul	NA
Loring	Very large fruit. Red skin. Yellow flesh. Freestone.	late Jul	Aug	late Aug	late Aug	Aug	NA
Nectar	White flesh. Pink skin. Excellent flavor.	late Jul	late Jul	mid-Aug	early Aug	Aug	NA
O'Henry	One of the best. Large fruit. Yellow flesh. Freestone.	late Jul	late Jul	mid-Aug	early Aug	Aug	NA
Redhaven	Yellow. Semifreestone. Needs heavy thinning.	early Jul	Jul	late Jul	late Jul	Jul	NA
Rio Oso Gem	Very large fruit. Yellow flesh. Freestone.	Aug	late Aug	Sep	Sep	Sep	Sep

PEACH SCION CULTIVARS cont.

Peach scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Springcrest	Medium sized. Yellow flesh. Semi-freestone.	early Jun	mid-Jun	late Jun	late Jun	late Jun	NA
Suncrest	Large fruit. Yellow flesh. Freestone. Midseason.	early Jul	Jul	late Jul	late Jul	Jul	NA
Veteran	Red blush. Elberta-type. Freestone. Dependable, heavy producer, excellent flavor.	late Jul	Aug	late Aug	late Aug	Aug	NA
low chill	These peach cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements.	August Pride, Babcock, Bonita, Desertgold, Early Amber, Earligrande, FloridaGrand, FloridaPrince, Midpride, Tropic-Berta, TopicSweet					

Plum and Prune

Figure 16.21

European plums (can be dried as prunes). *Photo:* P. M. Vossen.

Figure 16.22

Japanese plums. *Photo:* P. M. Vossen.

Plum *(Prunus domestica, Prunus salicina)* trees are one of the best-adapted fruit trees for almost anywhere in California. They are easy to grow. Available rootstocks are very tolerant of wet winter soil; they bloom late enough to avoid most spring frosts; and they have few pest problems. Plum trees get relatively large and require spacing of 12 to 18 feet. Most plums, but not all, require cross-pollination to set adequate crops; plan to plant two different cultivars. There are two different kinds of plums: Japanese *(Prunus salicina)* and European *(Prunus domestica)*. European types are either very sweet fresh plums or plums used for drying (prunes) (fig. 16.21). Most Japanese plums bloom earlier and mature earlier than European plums, and they typically require less chilling (fig. 16.22). Both types of plums require about 140 to 170 days to mature.

PLUM AND PRUNE ROOTSTOCKS

Plum and prune rootstocks	Comments
Citation	A new peach-plum hybrid that produces a full-sized tree. Tolerates wet soil.
Lovell Peach	Less susceptible to bacterial canker, but the most intolerant of heavy soil, wet feet, oak root fungus, and root rots. Produces a moderately large tree that fruits earlier and sets more consistent crops. Compatible with most plum or prune cultivars.
Marianna 2624	The overall best choice. Resistant to oak root fungus, root rots, root knot nematodes, and crown gall, but susceptible to bacterial canker and root lesion nematode. A cutting that is shallow rooted and produces a smaller tree. It is the best adapted to poor, wet soil conditions, but tends to sucker.
Myrobalan 29C	A cutting selection immune to root knot nematodes. Susceptible to oak root fungus, root rot, and root lesion nematode. Produces a tree with just a little less vigor than the Myrobalan seedling.
Myrobalan Seedling	The largest and most vigorous of the plum or prune rootstocks. Hardy, long-lived, adapted to most soil. Tolerates wet winter soil conditions. Susceptible to oak root fungus and nematodes, but somewhat resistant to root and crown rots.
Prunus besseyi	Semidwarfing rootstock. Suckers profusely. Produces inferior fruit quality on the scion cultivar. Partially incompatible with all plum cultivars.

PLUM SCION CULTIVARS

Plum scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Autumn Rosa	Large. Purple skin. Self-fertile. Japanese plum.	late Aug	late Aug	Sep	Sep	Sep	NA
Beauty	Green skin, amber flesh, heart shaped. Poor keeper. Japanese plum.	Jun	Jun	Jul	Jul	Jun	Jun
Burgundy	Red skin and flesh. Self-fertile. Holds well.	early Aug	early Aug	late Aug	late Aug	Aug	Aug
El Dorado	Purple skin. Amber flesh. Large, oblong.	early Jul	mid-Jul	Aug	Jul	Jul	Jul
Elephant Heart	Purple skin. Large, heart shaped. Japanese plum.	early Aug	early Aug	late Aug	late Aug	Aug	NA
Friar	Black skin. Firm, amber flesh. Mild flavor. Japanese plum.	mid-Aug	mid-Aug	late Aug	late Aug	Aug	Aug
Golden Nectar	Large. Yellow flesh. Tender skin. Great flavor. Japanese plum.	late Aug	late Aug	Sep	Sep	Sep	NA
Howard Wonder	Large, pink skin. Yellow flesh. Japanese plum.	early Aug	early Aug	late Aug	late Aug	Aug	NA
Kelsey	Green-yellow skin and flesh. Japanese plum.	early Aug	early Aug	late Aug	late Aug	Aug	Aug
Laroda	Red-purple skin. Yellow flesh.	mid-Aug	mid-Aug	late Aug	late Aug	Aug	Aug
Mariposa	Green-yellow skin. Red flesh. Large, heart shaped. Japanese plum.	Aug	Aug	late Aug	late Aug	Aug	Aug
Nubiana	Purple-black skin. Yellow flesh. Oblong. Japanese plum.	early Aug	early Aug	late Aug	late Aug	Aug	NA
President	Large. Blue skin. Yellow flesh. European plum.	late Aug	late Aug	Sep	Sep	Sep	NA
Red Beauty	Red skin, yellow flesh, excellent flavor.	early Jun	early Jun	Jun	mid-Jun	Jun	Jun
Roysum	Light purple skin. Yellow flesh.	Sep	Sep	Oct	Oct	Oct	NA
Santa Rosa	Purple skin. Amber flesh. Excellent flavor. Japanese plum.	early Jul	early Jul	late Jul	mid-Jul	Jul	Jul
Satsuma	Red skin and flesh. Small, round. Japanese plum.	early Aug	early Aug	late Aug	late Aug	Aug	Jul
Shiro	Light green–yellow skin. Yellow flesh.	early Jul	early Jul	late Jul	mid-Jul	Jul	NA
Simka	Dark black skin. Yellow flesh. Oblong.	early Aug	early Aug	late Aug	late Aug	Aug	NA
Sprite Cherry Plum	Black, sweet skin. Exotic flavor. Small.	early Aug	early Aug	late Aug	late Aug	Aug	NA
Wickson	Green-yellow skin. Yellow flesh. Large, heart shaped. Japanese plum.	Jul	Jul	Aug	Aug	late Jul	NA
low chill	These plum cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements.	Beauty Burgundy, Delight, Howard Wonder, Kelsey, Mariposa, Meredith, Methley, Santa Rosa, Satsuma, Sprite					

PRUNE SCION CULTIVARS

Plum scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
French	Medium-sized fruit. Self-fertile. Late maturing. European plum.	Aug	Aug	late Aug	late Aug	Aug	NA
Green Gage	Greenish yellow skin. Amber flesh. Old, European plum.	Aug	Aug	late Aug	late Aug	Aug	NA
Imperial	Large fruit. Requires cross-pollination. Late maturing. European plum.	Aug	Aug	late Aug	late Aug	Aug	NA
Italian	Large fruit. Purple skin. Yellow flesh. European plum.	Aug	Aug	late Aug	late Aug	Aug	NA

Plum-Apricot Hybrids

Plum-apricot hybrids (*Prunus salicina* × *Prunus armeniaca*), which include pluot, plumcot, and aprium, are relatively new tree fruits that are unique in that they are a cross between two similar species that normally do not cross. The fruits resemble plums (pluot) with smooth skin and more narrow leaves or apricots (aprium) with fuzzy skin and wider leaves; plumcots are variable and intermediate between these two. These hybrids are being grown commercially and some are offered to home gardeners for production. Their primary characteristics are that they have excellent, unusual fruit quality. They require cross-pollination in most cases, so more than one cultivar of each type is needed. Their exact pollination requirements are not known, so it would be best to have at least one or more different plumcots, plums, pluots, apriums, or apricots in the vicinity as a pollen source. They also tend to take longer than nonhybrids to set fruit, usually 5 to 7 years. They tend to grow quite vigorously and may require summer pruning to maintain size within limited spaces.

PLUM-APRICOT HYBRID ROOTSTOCKS

Plum-apricot hybrid rootstocks	Comments
Citation	A new peach-plum hybrid that produces a full-sized tree. Tolerates wet soil.
Marianna 2624	The overall best choice. Resistant to oak root fungus, root rots, root knot nematodes, and crown gall, but susceptible to bacterial canker and root lesion nematode. A cutting that is shallow rooted and produces a smaller tree. It is the best for poor, wet soil conditions but tends to sucker.
Myrobalan 29C	A cutting selection that is immune to root knot nematodes. Susceptible to oak root fungus, root rot, and root lesion nematode. Produces a tree with just a little less vigor than trees on Myrobalan Seedling.
Myrobalan Seedling	The largest and most vigorous of the plum or prune rootstocks. Hardy, long-lived, adapted to most soil. Tolerates wet winter soil conditions. Susceptible to oak root fungus and nematodes but somewhat resistant to root and crown rots.

PLUM-APRICOT HYBRID SCION CULTIVARS

Plum-apricot hybrid scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast Foothills	Sierra Nevada Foothills	Southern California
Flavor Supreme	Pluot. Green to brown skin. Red, juicy flesh. Excellent size and flavor.	early Jun	mid-Jun	Jul	Jul	Jul	NA
Flavor King	Pluot. Red-purple skin. Good size, irregular ripening, sweet flavor. Cross-pollinated with Flavor Grenade, Beauty Plum, or Burgundy Plum.	early Aug	mid-Aug	late Aug	late Aug		NA
Flavor Queen	Pluot. Green-golden skin. Yellow, firm flesh. Good size. Excellent, very sweet flavor.	late Jul	mid-Jul	Aug	Aug	Aug	NA
Flavor Grenade	Pluot. Green skin with red blush. Elongated shape, excellent flavor. Best pollinated with Burgundy plum.	early Aug	mid-Aug	late Aug	late Aug	late Aug	NA
Flavorella	Plumcot. Golden yellow skin. Very sweet, excellent flavor.	early Jun	mid-Jun	Jul	Jul	Jul	NA
Flavor Ann	Aprium. Golden skin and flesh. Strong, sweet apricot flavor.	mid-May	late May	Jun	Jun	Jun	NA
Flavor Delight	Aprium. Golden skin and flesh. Strong, sweet apricot flavor. Reliable production. Sets best with cross-pollination from an apricot.	mid-May	late May	Jun	Jun	Jun	NA
low chill	These cultivars are adapted to the low elevations of southern California.	Flavor King, Flavor Grenade, and Flavor Delight					

Nut Crops

Almond

Figure 16.23

Healthy almond fruit. *Photo:* J. K. Clark.

Almonds (*Prunus dulcis*, formerly *Prunus amygdalus*) (fig. 16.23) are stone fruits that are consumed as nuts. All almonds produced commercially in the United States are grown in California. The earliest to bloom of stone fruits (February); generally do poorly in North Coast counties, where they bloom when weather is cold and rainy. Very susceptible to spring frosts. Almonds do not tolerate wet soil. The Central Valley and drier regions of southern coast are very favorable for almonds. Trees are very susceptible to being killed by bacterial canker. Cross-pollination is required; all cultivars are self-unfruitful, and some are cross-unfruitful due to incompatibilities. Almonds are harvested by shaking trees when hulls begin to split. Almonds need 180 to 240 days to mature nuts. After harvest, the nuts (embryo and shell) are dried to a minimum moisture content.

ALMOND ROOTSTOCKS

Almond rootstocks	Comments
Almond Seedling	Long-lived, deep rooted; needs well-drained soil. Not used much due to disease susceptibility.
Lovell Peach	Produces a smaller tree than almond rootstock; susceptible to many diseases and high salts.
Mariana 2624 Plum	Marginally compatible with most almond cultivars.
Almond-Peach hybrids	New stocks that are nematode resistant and vigorous. Higher yielding; susceptible to ring nematode and bacterial canker.
Nemaguard Peach	Nematode resistant; good for sandy soil.

ALMOND SCION CULTIVARS

Almond scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Carmel	Excellent quality. Nut well sealed in the shell. Excellent pollenizer.	Aug	Aug	Sep	Sep	Aug	Aug
Mission	Late-blooming, productive tree. Hard shell, short kernel.	Aug	Aug	Sep	Sep	Aug	Aug
Neplus Ultra	Large, soft-shelled nut. Long, flat kernel. Good pollenizer.	Aug	Aug	Sep	Sep	Aug	Aug
Nonpareil	The most popular paper-shelled cultivar. Interfruitful with Price, Mission, Carmel.	Aug	Aug	Sep	Sep	Aug	Aug
Price	Very similar to Nonpareil. A good pollenizer.	Aug	Aug	Sep	Sep	Aug	Aug

Chestnut

Figure 16.24

Chestnuts without the burr: with the hull, without the hull but with the pellicle, and nut meat without the pellicle. *Photo:* P. M. Vossen.

Little research has been done on the chestnut (*Castanaea* spp.) in California (fig. 16.24). Thus, we know little about its specific adaptability or productive capacity. Chestnuts are monoecious (separate female and male flowers are borne on one plant, like walnuts), and some cultivars are self-unfruitful; thus, two different cultivars should be grown for cross-pollination to produce consistent crops. Trees reach a height of 80 feet and spread to 60 feet under ideal conditions. Chestnuts are excellent and fruitful shade trees if grown in very well drained soil. Chestnuts are almost pest-free in California but are very susceptible to root rot. Seedling is the only known rootstock. Edible chestnuts should not be confused with the poisonous horse chestnut (*Aesculus californica*). Fresh chestnuts contain about 50% moisture. Unlike other nuts, chestnuts have low oil content (8%).

CHESTNUT CULTIVARS

Chestnuts	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Colossal	The industry standard and the overall best choice. Large fruited. Excellent quality. Parentage unknown.	early Oct	early Oct	late Oct	late Oct	mid-Oct	early Oct
Dunstan	A cross of American and Chinese cultivars. Medium-small nuts. Sweet, and blight resistant. Late flowering.	early Oct	early Oct	late Oct	late Oct	mid-Oct	early Oct
Eurobella	Large nut. Good pollenizer for Colossal.	early Oct	early Oct	late Oct	late Oct	mid-Oct	early Oct
Seedling	Not a named cultivar. Each tree is genetically different. Unknown fruit quality. Unknown tree shape and fruit size. Only known rootstock.	early Oct	early Oct	late Oct	late Oct	mid-Oct	early Oct
Silverleaf	Medium-sized nut. Good pollenizer for Colossal, but shell splits are a problem.	early Oct	early Oct	late Oct	late Oct	mid-Oct	early Oct
others	These cultivars are available for trial.	Castel del Rio, Fowler, Marrone di Maradi, Montesol					

Filbert (Hazelnut)

The nut-bearing filbert (*Corylus* spp.) plants grow naturally as suckering shrubs but can be trained as trees by continually removing the suckers. They reach a height of 15 to 20 feet with an even greater spread. Filberts are monoecious (separate male and female flowers on the same plant, like walnuts) but are self-unfruitful; cross-pollination is required to set fruit, so two different cultivars must be planted. Crop production is not consistent in California, which may be due to summer heat, which causes catkins (male flowers) to fall off prematurely. Filberts are grown on their own roots. They need a 180-day growing season. Filbert fruit (fig. 16.25) are contained in a spiny burr that turns brown and splits into sections.

Figure 16.25

Filberts, or hazelnuts, in the shell. *Photo:* P. M. Vossen.

FILBERT CULTIVARS

Filberts	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Barcelona	The old industry standard. Use Davianna or Du Chilly as pollenizer.	Sep	Sep	Oct	late Sep	late Sep	NA
Brixnut	A secondary main production nut. Use Davianna or Du Chilly as a pollenizer.	Sep	Sep	Oct	late Sep	late Sep	NA
Butler	Pollenizer for Ennis.	Sep	Sep	Oct	late Sep	late Sep	NA
Davianna	Use Barcelona or Du Chilly as a pollenizer.	Sep	Sep	Oct	late Sep	late Sep	NA
Du Chilly	Use Barcelona or Davianna as a pollenizer.	Sep	Sep	Oct	late Sep	late Sep	NA
Ennis	A new cultivar that has better quality than Barcelona. Use Butler as a pollenizer.	Sep	Sep	Oct	late Sep	late Sep	NA
White Aveline	General pollenizer.	Sep	Sep	Oct	late Sep	late Sep	NA

Pecan

Pecans *(Carya illoensis)* are not a good choice for northern California. They require a deep, well-drained soil, a hot climate to mature the nuts properly, and adequate soil moisture. At least two different cultivars must be planted for good pollination, because even though pecans are largely self-fertile, the flowers are dichogamous, which means that there is little overlap between pollen shedding and stigma receptivity. Most cultivars require at least 180 days for nuts to mature. Commercial production in California is limited to the southern San Joaquin Valley. Pecans are native to the United States and grow well in the south-central states. Their native range extends into the Midwest; cultivars grown there tolerate cold winters and short growing seasons. The cultivars listed here require a very long growing season and freedom from frost. They can be tried in the warmest regions of the state. The trees get as large as walnut trees. Pecans are grown on seedling rootstocks.

PECAN SCION CULTIVARS

		Harvest					
Pecans	**Comments**	**San Joaquin Valley**	**Sacramento Valley**	**Central Coast**	**North Coast**	**Sierra Nevada Foothills**	**Southern California**
Apache	Late pollen shed. Early receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Barton	Early pollen shed and receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Bradley	Excellent pollenizer for Western Schley.	Oct	late Oct	NA	NA	late Oct	late Oct
Choctaw	Late pollen shed. Early receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Comanche	Late pollen shed. Early receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Shawnee	Early pollen shed. Midseason receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Sioux	Early pollen shed and receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Western Schley	Early pollen shed and receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct
Wichita	Late pollen shed. Early receptivity.	Oct	late Oct	NA	NA	late Oct	late Oct

Pistachio

Pistachio *(Pistacia vera)* trees require long, hot, dry summers and mild winters. April frosts kill flowers, and cool summers do not promote good kernel development. Adequate winter chilling and good weather during bloom (pistachio is wind pollinated) are required. Pistachios are a poor choice for coastal California and will not produce fruit (fig. 16.26) in low elevations of southern California. Most other warm regions in the state are adapted for backyard pistachio production. Pistachio trees are dioecious (male and female trees); male trees must be planted near female trees to get a good crop set. Trees become large and should be planted about 20 feet apart.

Figure 16.26

Pistachios. *Photo:* W. Suckow and E. Kilmartin.

PISTACHIO ROOTSTOCKS

Pistachio rootstocks	Comments
Pistacia atlantica	Resistant to many nematodes, but susceptible to cold (below 15°–20°F) and Verticillium wilt.
Pistacia integerrima	Resistant to Verticillium. Very susceptible to cold damage.
Pistacia terebinthus	The best rootstock. Most tolerant of cold. Resistant to nematodes. Susceptible to Verticillium wilt.

PISTACHIO SCION CULTIVARS

		Harvest					
Pistachios	Comments	San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California*
Joley	Female. Smaller nuts. Fewer blanks. More splits.	Oct	late Oct	NA	NA	late Oct	late Oct
Kerman	Female. Best nut-producing cultivar.	Oct	late Oct	NA	NA	late Oct	late Oct
Peters	Male. Good for pollination.	Oct	late Oct	NA	NA	late Oct	late Oct
Sfax	Smaller, good-quality nuts.	Oct	late Oct	NA	NA	late Oct	late Oct

**Note:* Pistachio may not produce well in most areas of southern California.

Walnut

Walnuts (*Juglans regia, Juglans hindsii*) need a deep, well-drained soil (3–5 ft). Shoots, particularly blossoms, do not tolerate frosts. Once growth begins in the spring, rainy weather can cause severe losses due to walnut blight. Trees range in size from very large (80 ft tall) to medium height (40–50 ft tall). They require a spacing of 30 to 60 feet. Walnut culture has changed drastically in the last few years due to the introduction of new cultivars. Production in coastal climates should be limited to the late-leafing cultivars. Walnuts are monoecious (separate male and female flowers on one tree) and dichogamous (pollen is shed when female flowers are not receptive); two different cultivars must be planted to ensure overlapping bloom periods, fertilization, and fruit set. The fruit exhibit various colorations (fig. 16.27).

Figure 16.27

Walnuts, showing different nut meat coloration. *Photo:* P. M. Vossen.

WALNUT ROOTSTOCKS

Walnut rootstocks	Comments
Black Walnut	This has been the standard rootstock in California, known as Northern California Black Walnut. It is resistant to oak root fungus but susceptible to crown rot, root rot, root lesion nematode, and blackline virus.
English Walnut	This rootstock is a seedling of English walnut. It is very susceptible to oak root fungus but less susceptible to blackline virus. It is the least tolerant of wet soil.
Paradox	The best rootstock choice, in general. A hybrid between Black Walnut and English Walnut. Very vigorous. Tolerates poorer soil conditions than the others. Less susceptible to crown and root rot. Susceptible to crown gall and blackline virus.

STANDARD WALNUT SCION CULTIVARS

Standard walnut scions	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Chandler	Best choice for coastal California. New cultivar. 80% fruitful lateral buds. Produces a smaller tree that requires careful pruning and training. Blooms late. Leafs out late.	Oct	late Oct	late Oct	late Oct	late Oct	NA
Hartley	The main cultivar grown in California. Excellent-quality nuts. Huge tree but requires little pruning. 5% fruitful lateral buds. Leafs out late, blooms late. Good choice.	Oct	late Oct	late Oct	late Oct	late Oct	NA
Howard	Good choice. New cultivar. 80% fruitful lateral buds. Produces a smaller tree that requires careful pruning and training. Blooms late. Leafs out late.	Oct	late Oct	late Oct	late Oct	late Oct	NA
Mayette	Old-time cultivar. Plant as a pollenizer for late-blooming cultivars. Poor producer. Leafs out late. Blooms late. Large tree.	Oct	late Oct	late Oct	late Oct	late Oct	NA
S. Franquette	Old-time cultivar. Should be planted as a pollenizer for the late-blooming cultivars. Poor producer. Leafs out late. Blooms late. Large tree, but requires little pruning.	Oct	late Oct	late Oct	late Oct	late Oct	NA
Tehama	Good choice. New cultivar. 80% fruitful lateral buds. Produces a smaller tree that requires careful pruning and training. Blooms late. Leafs out late.	Oct	late Oct	late Oct	late Oct	late Oct	NA

BLACK WALNUT SCION CULTIVAR

Black walnut scion	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Seedling	Not a true cultivar. Seedlings of Northern California Black Walnut trees.	Oct	late Oct	late Oct	late Oct	late Oct	NA

EASTERN BLACK WALNUT SCION CULTIVARS

Eastern black walnut scions	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Thomas, Ohio, and Meyers	Cultivars that may be worthy of consideration.	Oct	late Oct	late Oct	late Oct	late Oct	NA

Vines

Kiwifruit

Figure 16.28

Green and golden kiwifruit. *Photo:* P. M. Vossen.

Kiwifruit (*Actinidia deliciosa*, formerly *A. chinensis*) is a large, frost-sensitive, temperate zone vine that requires plenty of heat to mature the fruit properly. Kiwifruit do well when grown in warm sites on a trellis or arbor protected from the wind. Soil must be well drained but kept moist at all times. Kiwifruit can tolerate temperatures as low as 10°F in January but only if fall temperatures gradually decrease over several days. Late-spring frosts and early-fall frosts will kill vines. Overhead frost protection is desirable. As noted below, fuzzy cultivars are not as cold-hardy as smooth-skin cultivars. Plant kiwifruit about 15 to 20 feet apart. The plants are functionally dioecious. Successful fruit production requires a female cultivar and a male with viable pollen when the female is receptive. Vines leaf out in March, bloom occurs in May, and fruit (fig. 16.28) are harvested in late September, October, and November.

KIWIFRUIT ROOTSTOCKS

Kiwifruit rootstocks	Comments
Cutting	Own rooted. From ½-inch-diameter midsummer wood or dormant wood. Grows back after frost damage.
Seedling	Extracted seed from ripe kiwifruit.

FUZZY KIWIFRUIT SCION CULTIVARS

Fuzzy kiwifruit scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Chico	Male vine used to pollinate Hayward, 8:1 ratio.		I				
Hayward	The commercial female cultivar grown in California. Large fruit. Excellent flavor. Will ripen on the vine but can be picked when still hard, placed in cold storage (32°F), and removed to room temperature for final ripening. Will keep for up to 6 months.	Oct	late Oct	late Nov	early Nov	Nov	NA
Matua	Male vine used to pollinate Hayward, 8:1 ratio.						
Tamori	Male vine used to pollinate Hayward, 8:1 ratio.						

SMOOTH-SKIN KIWIFRUIT SCION CULTIVARS

Smooth-skin kiwifruit scions	Comments	Harvest					
		San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Anna	Nickel-sized fruit. Unique flavor. Very productive.	late Sep	late Sep	Oct	early Oct	Oct	NA
Issai	Dime-sized fruit that requires no cross-pollination.	late Sep	late Sep	Oct	early Oct	Oct	NA
Ken's Red	Dime-sized fruit. Red flesh and skin. Excellent flavor.	late Sep	late Sep	Oct	early Oct	Oct	NA

LOW-CHILL KIWIFRUIT CULTIVARS

Low-chill cultivars	Comments
Abbott, Allison, Blake, Bruno, Elmwood, Tewi, Vincent	These kiwi cultivars are adapted to the low latitudes of southern California because they have low winter chilling requirements (50–250 hours).

Miscellaneous Temperate Fruits

Fig

Figs (*Ficus carica* L.) can be grown easily, but they require a protected location in the cooler parts of the state because they require heat to mature the fruit properly. Fig trees do best in well-drained soil but will tolerate wet soil better than most other fruit trees. Gophers must be controlled. Figs are grown on their own roots from cuttings. Trees reach a height of 20 to 30 feet with an equal spread but can be pruned to a smaller size. Most cultivars require no cross-pollination. Several cultivars set fruit (fig. 16.29) parthenocarpically, and several cultivars have two crops per year (shown below as "Jun/Sep"). The breba crop (first crop) matures in midsummer in 100 to 120 days, and the second crop matures in late summer or fall. Figs require very little winter chilling and are considered a borderline temperate zone species by many pomologists. The Smyrna types require caprification (pollination by Capri figs nearby).

Figure 16.29

Fig fruit. *Photo:* P. M. Vossen.

FIG SCION CULTIVARS

		Harvest					
Fig scions	Comments	San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Adriatic	Good fresh but especially good for drying. Yellow skin and amber flesh.	Jun/Sep	Jun/Sep	Oct	Oct	Jun/Sep	Jun/Sep
Black Mission	The most dependable cultivar for the home orchard. Purple-black skin with red flesh.	Jun/Sep	Jun/Sep	Nov	Nov	Jun/Sep	Jun/Sep
Brown Turkey	Large fruit. Excellent quality. Purple-green skin. Red flesh.	Jun/Sep	Jun/Sep	Nov	Nov	Jun/Sep	Jun/Sep
Italian Everbearing	Brown. Turkey type. Very prolific.	Jun/Sep	Jun/Sep	Nov	Nov	Jun/Sep	Jun/Sep
Kadota	Requires high temperatures and a long growing season to perform well. Yellow-green fruit with amber flesh. Produces both a breba and a second crop with moderate pruning.	Jun/Sep	Jun/Sep	Nov	Nov	Jun/Sep	Jun/Sep
Osborn	Performs well only in cool coastal areas. Purple-bronze fruit with amber flesh. Very prolific.	Jun/Sep	Jun/Sep	Oct	Oct	Jun/Sep	Jun/Sep
Smyrna-type	Requires cross-pollination by the Capri fig female wasp to produce a crop. Capri figs containing female wasps may be difficult to locate for backyard fruit tree producers.	Jun/Sep	Jun/Sep	Nov	Nov	Jun/Sep	Jun/Sep
White Genoa	Good for coastal locations. Large fruit. Yellow-green, thin skin. Strawberry flesh. Ripens when others won't.	Jun/Sep	Jun/Sep	Oct	Oct	Jun/Sep	Jun/Sep

Olive

The olive (*Olea europaea L.*) tree is an evergreen tree that performs best in hot, dry areas of California; it does not tolerate wet winter soil or temperatures below about 22°F. It is an attractive ornamental and produces table fruit and oil. Crop production is irregular under cool coastal conditions. Rooted cuttings are used without specific rootstocks. Space trees 16 to 20 feet apart. Olives for canning and pickling are usually harvested in September and October in California. Cultivars are divided into table and oil types (fig. 16.30), but only because of fruit size, as any olive can be pickled for eating or crushed for oil. Some new cultivars grown specifically for oil have recently been imported into California from the Mediterranean countries.

Figure 16.30

Various table and oil olive cultivars. *Photo:* P. M. Vossen.

TABLE OLIVE CULTIVARS

Table olives	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Ascolano	Large-fruited cultivar, the most cold-hardy of all table cultivars in California. Large fruit. Oil is very aromatic.	late Sep	early Oct	mid-Oct	mid-Octt	mid-Oct	Oct
Manzanillo	The main cultivar used for the black California-style olive. Low, spreading, medium-sized tree, early-maturing fruit with a medium oil content. Trees are susceptible to cold injury, peacock spot, and olive knot.	late Sep	early Oct	mid-Oct	mid-Oct	mid-Oct	Oct
Mission	Medium-sized fruit, high oil content, cold-hardy, susceptible to foliar diseases.	late Sep	early Oct	mid-Oct	mid-Oct	mid-Oct	Oct
Sevillano	Largest fruit. Very susceptible to olive fly. Produces interesting, herbal-flavored oil.	late Sep	early Oct	mid-Oct	mid-Oct	mid-Oct	Oct

OIL OLIVE CULTIVARS

Oil olives	Comments	Harvest: San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Arbequina	A cultivar from northern Spain that produces a very high quality fruity oil. Fruit is small. Very fruitful. One of the most cold tolerant.	mid-Nov	late Nov	early Dec	early Dec	late Nov	late Nov
Coratina	A cultivar from southern Italy that ripens very late. Very high oil content and very high in poly-phenols. Regular bearing but sensitive to cold.	Nov–Dec	Nov–Dec	Dec–Jan	Dec–Jan	Dec	Nov–early Dec
Frantoio	Italian cultivar with a high oil content that is very aromatic, floral, and grassy. Not adapted to hot desert areas. Cold-sensitive.	mid-Nov	late Nov	Dec	early Dec	late Nov	late Nov
Leccino	Italian cultivar used in olive oil blends with Frantoio. Ripens a little earlier than other cultivars. Cold-hardy.	mid-Nov	late Nov	Dec	early Dec	late Nov	late Nov
Maurino	Italian cultivar used in olive oil blends. Very flavorful, spicy oil.	mid-Nov	late Nov	Dec	early Dec	late Nov	late Nov
Pendolino	Italian cultivar used in olive oil blends. Also used as a pollenizer. Cold-hardy.	mid-Nov	late Nov	Dec	early Dec	late Nov	late Nov
Picual	Spanish cultivar used for oil and table fruit. Very high in polyphenols and oil. Very fruity. Ripens early, easy to harvest. Cold-hardy.	Nov	Nov	early Dec	early Dec	late Nov	Nov

Persimmon

Persimmons (*Diospyros kaki*) are very good fruit trees for home planting. They bloom late, avoiding spring frosts, and they do not require much winter chilling. They perform well throughout the state. Persimmon trees do not need ideal soil. They will tolerate wet feet in winter and dry conditions in the summer. The fruit (fig. 16.31) are almost pest-free. Cross-pollination is not usually necessary. Cross-pollinated fruit will have seed; whereas, fruit from a lone tree probably will not.

Figure 16.31

Persimmon. *Photo:* P. M. Vossen.

PERSIMMON ROOTSTOCKS

Persimmon rootstocks	Comments
Diospyros kaki	An adequate rootstock. Produces a long taproot and small, branching, fibrous roots.
Diospyros lotus	Most widely used seedling rootstock. Best choice. Compatible with most cultivars. Tolerates wet soil.
Diospyros virginiana	This native species produces a very good, fibrous root system, tolerates drought and excess moisture fairly well, but may sucker profusely and may produce trees of variable size.

PERSIMMON SCION CULTIVARS

		Harvest					
Persimmon scions	Comments	San Joaquin Valley	Sacramento Valley	Central Coast	North Coast	Sierra Nevada Foothills	Southern California
Baru	Round; orange skin. Sweet brown flesh.	Oct	late Oct	Nov	Nov	late Oct	late Oct
Diospyros virginiana	Native species, not a cultivar. Very small, very flavorful fruit. Must be eaten when soft.	Oct	late Oct	Nov	Nov	late Oct	late Oct
Fuyu	Large, flat; orange-red color. Flesh is firm like an apple and nonastringent when ripe. Cross-pollination is not required, but when present, fruit will have seed. Trees are smaller, requiring 14–16 ft. Fruit loses astringency at maturity while still firm and crunchy.	Oct	late Oct	Nov	Nov	late Oct	late Oct
Hachiya	Large, deep orange-red, acorn-shaped fruit. Flesh turns brown around the seed and must be very soft to eat. Does not need cross-pollination. Trees get large and require 20 ft. Fruit is astringent until very ripe and soft.	Oct	late Oct	Nov	Nov	late Oct	late Oct
Hyakume	Cinnamon-chocolate-colored flesh.	Oct	late Oct	Nov	Nov	late Oct	late Oct

Planting and Care

Site Selection

When planning to grow deciduous fruits and nuts in the garden, consider the climate, soil, drainage, light intensity, and the diurnal temperature pattern at the proposed site. Fruit trees must be grown in full sun; even small amounts of shade reduce flower bud formation and fruit set. Fruit quality is influenced by temperature and light during the growing season, as well as by the gardener's cultural practices and the genetic potential of the cultivar. Planting sites near a large body of water can moderate temperature; in contrast, mountain sites at high elevations usually experience extremes of hot and cold, which is the most difficult condition for fruit trees. North-facing sites are colder and tend to retard bud development in the spring; south-facing sites accelerate development. The delay of bloom typical of north-facing sites can be an advantage in avoiding frost injury. Since flowers and young fruit are more tender than mature fruit, spring frosts are much more damaging than early-fall frosts. If frosts or cold, rainy spring weather are common, early-blooming crops such as apricots and almonds become very difficult to grow. Many peaches and plums bloom later, but still 15 to 20 days before cherries, apples, and pears. The fruit tree species and cultivar should be selected to reduce the risk of early-spring frosts and late-spring rains at the site.

Figure 16.32

Mound planting. *Photo:* P. M. Vossen.

If a soil nutrition problem is suspected at the planting site, the soil should be tested for pH and analyzed for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na). Necessary amendments should be applied prior to planting to adjust nutrient levels and to achieve a pH of approximately 6 to 7 (see chapter 3, "Soil and Fertilizer Management," for details on adjusting pH). Phosphorus deficiency is very rare in California; low potassium is more common. The calcium-to-magnesium ratio for temperate fruits should be at least 1:1 and up to 5:1 in favor of calcium. Soil with an extremely high level of magnesium is rare, but it is very difficult to grow fruit trees in it. Nitrogen (N) is not usually tested for in soil because this element is so mobile and will almost always need to be added annually. Levels of micronutrients, such as zinc (Zn), boron (B), manganese (Mn), iron (Fe), and copper (Cu), are determined by analyzing specific portions of the plant tissue and by observing color changes in the leaves. Micronutrient testing for deficiencies or excesses is usually done only if a specific problem is common in the area or is suspected to be causing a problem in tree performance. Soil and plant tissue testing are most accurately done by a certified laboratory.

For good tree growth, the soil should be very well drained and about 3 to 5 feet deep. Shallow, poorly drained sites produce smaller, weaker trees with lower yields. Such trees have more pest problems and require special water management practices. Soil compaction should be corrected by deep digging prior to planting. In areas with heavy winter rainfall or very heavy clay soil that drains poorly, drainage can be improved by planting the trees on raised mounds (fig. 16.32). Home gardeners can also modify the

planting site by installing planter boxes, raised beds, and drainage systems to improve tree performance. If good soil is added to a planting site, it should always be mixed in so that there is a gradual change from one soil to the next without layering.

Planting Bare-Root Trees

Temperate fruit and nut crops are usually purchased and planted as bare-root trees. These trees benefit from mound or raised bed planting (fig. 16.33). Mound planting is especially helpful for improving growth and reducing root and crown rots in apple, chestnut, walnut, fig, cherry, apricot, almond, and peach rootstocks. Bare-root trees should never be planted in saturated or wet soil. Work the ground in the fall, add amendments if needed, and cover it if necessary to keep it dry. Bare-root trees can be planted anytime, but because they do best when they develop new roots and shoots during cool spring weather, they are usually planted in the winter or early spring. Roots of bare-root trees should never be allowed to dry out. Keep them in moist organic matter or dig a shallow trench and bury the roots temporarily before planting.

The most fragile part of a tree is the crown, the transitional section at or just below the soil surface where the trunk joins the roots (fig. 16.34). When planting the tree, plant it high, keeping the crown area above the original soil line (see the bud union on fig. 16.33). The crown should be kept as dry as possible, especially in the spring when the tree is leafing out. Raised planting prevents soil saturation near the trunk and crown areas. Do not plant the trees in a basin. If the planting area is too dry, it should be thoroughly watered a few days prior to planting, and the trees should be watered right after planting. After the tree is planted, apply compost, wood chips, grass clippings, or other mulch material 3 to 4 inches deep in a radius 2 to 3 feet from the trunk for weed control and nutrient enhancement. Do not dig a large hole and fill it with amended soil containing organic materials, sand, or additives like perlite, vermiculite, peat, or lava rock. This creates a pot-like situation where roots tend to remain in the more favorable root growing conditions of the amended soil instead of growing out into the native soil.

Follow these step-by-step instructions for mound planting (see fig. 16.33).

1. Prepare the soil by working an area about 16 square feet (4 ft by 4 ft). Dig just deep enough to remove any compacted layers.
2. Clip off broken, twisted, or girdling roots. Do not plant trees with rotted roots or warty growths on the roots (possibly due to crown gall caused by bacterial infection—see table 16.6). Return trees with these problems to the nursery for a refund. Do not overprune roots.
3. Place the tree on top of the ground, spreading the roots in all directions, and shovel soil from the surrounding area on top of the roots, forming a

Figure 16.33

Mound planting of temperate fruit and nut trees.

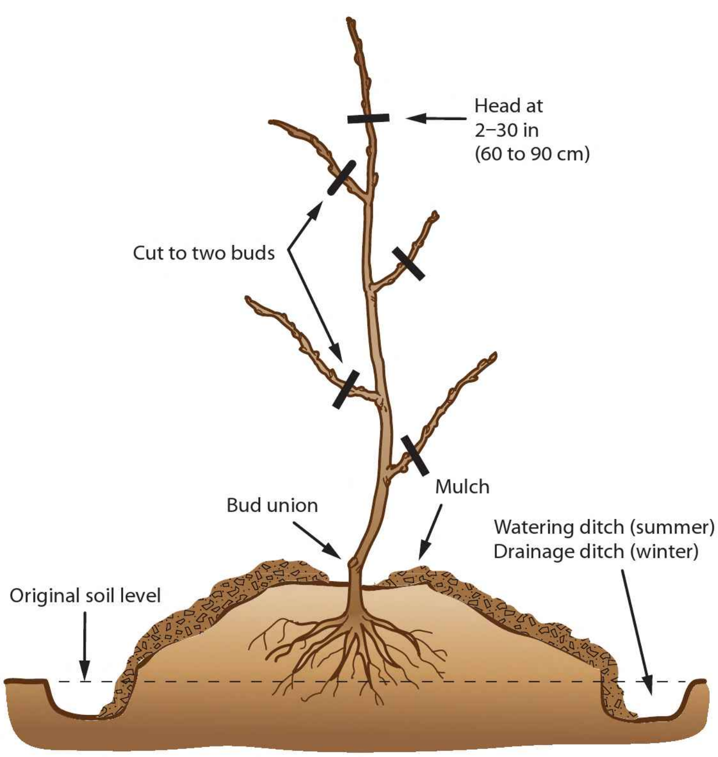
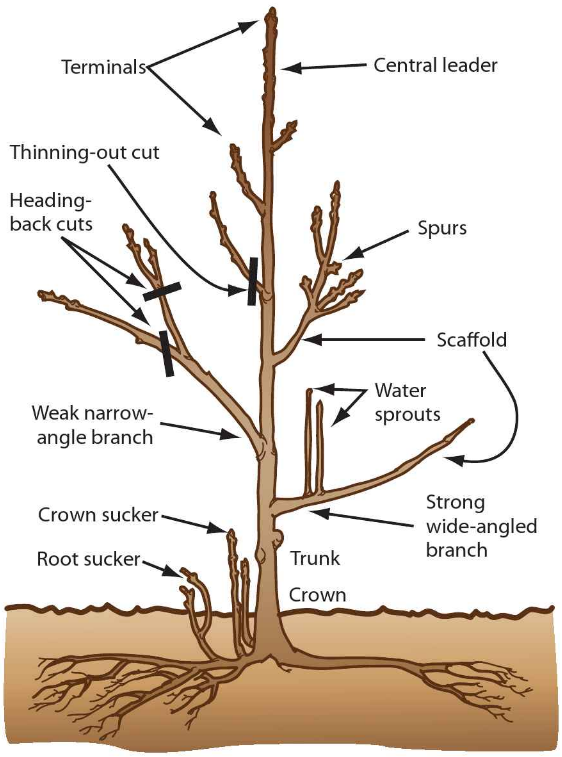


Figure 16.34

Fruit tree framework terms. *Source:* After Westwood 1993, p. 204.



mound. The ditch created can be used to water the tree the next spring and summer and will aid in winter drainage.

4. Head the tree at 20 to 24 inches from the top of the mound to encourage low branching and to balance the scion and root growth.
5. Cut back to two buds any lateral branches below 24 inches from the ground.
6. Paint the lower two-thirds of the tree trunk with a mixture of one-half water and one-half interior white latex paint to reduce sunburn and prevent attack by Pacific flathead borers (see table 16.6). Leaving the upper 6 to 8 inches unpainted increases bud break and reduces the chance of damaging the buds during painting; nonlatex paints will damage tender plant tissue.

Most homeowners and commercial growers want trees that do not get too tall and that bear fruit close to the ground for easy thinning and picking. The only way to get low branching on fruit trees, that is, branch formation originating on the main trunk below 2 feet from the ground, is to cut the top of the tree (heading or topping) at planting at 20 to 24 inches from the ground. New, vigorous growth occurs only within 6 to 8 inches of where the heading cut is made. Heading has little to no influence on the development of branches lower than that in the tree. Since the most vigorous growth occurs nearest the heading cut, heading trees too high at planting creates main branch development and most fruit production higher in the tree.

Training and Pruning

The five main reasons to prune a fruit tree are to train the tree for easy management (thinning, harvest, spraying); influence fruit size (grow larger fruit); regulate annual bearing; allow light into the lower portion of the tree; and improve vigor (renews the fruit-bearing wood). Over time, unpruned trees develop thicker canopies, which limits light penetration into the tree and results in poor flower bud formation, poor fruit set, and poor fruit color.

Training young trees

There are two primary training systems: the central leader system and the open center system (fig. 16.34). Which system to use depends upon the natural growth habit and structural form of the tree.

The central leader system (fig. 16.35A) employs an upright vertical trunk with three to ten primary scaffold limbs. These primary scaffold limbs should have wide crotch angles that are evenly distributed about the trunk and that are separated vertically from each other in two or three tiers. The lower primary scaffold limbs arise from the trunk at 45° to 60° angles and are longer than the upper primary limbs, which are at 70° to 90° angles to the trunk. Since the shorter upper branches

Figure 16.35

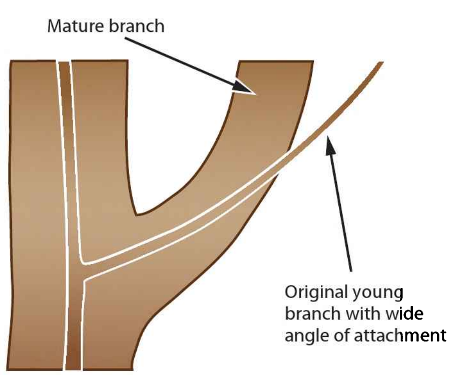
Central leader (A, apple) and open center (B, stone fruit) training systems. *Photos:* P. M. Vossen.

A

B

Figure 16.36

Growth of lateral branch with strong, wide-angled attachment. Note that the point of branch attachment remains large and strong. *Source:* After Westwood 1993, p. 169.



are attached at wider angles, their vigor is reduced, giving the tree a pyramid shape. The number of tiers depends on the ultimate tree height desired. This shape is good for light penetration, since the top does not shade the lower limbs. The narrower crotch angles of the four or five lower branches help them maintain vigor while producing 90% of the fruit.

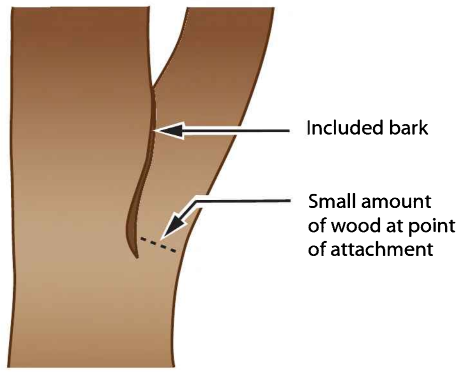
To create the central leader system in most trees, the young scaffold branches must be held in place at the appropriate angle for several months until they stiffen. Most scaffold limbs tend to grow excessively upright and must be propped outward with spreaders, weighted down with weights, or bent and tied down with string or tape. A combination of pruning and branch spreading is often needed to maintain a tree's shape. The central leader system works well for apple, pear, persimmon, and pecan.

The open center, or vase, training system (see fig. 16.35B) is based on development of three or four scaffold branches that emerge at wide crotch angles from a main trunk starting about 12 inches from the ground. Ideally, the branches have vertical spacing of about 6 inches between branches and are evenly spaced around the trunk. The primary scaffold branches originating at 45° to 60° angles from the trunk create an open tree center. This system creates an upside-down pyramid. To prevent the top from shading the lower limbs, the center must be open. This is the most common form used for peach, nectarine, pear, olive, plum, apricot, and cherry.

As a tree ages, the trunk grows over and around wide-angled branches, which makes their attachment very strong (fig. 16.36). A weak tree framework has narrow crotch angles and may have three or more scaffold branches arising from the same junction. The narrow crotch angle usually develops a bark inclusion between the branches and is a spot for debris and wood-rotting organisms to collect (fig. 16.37). As the weight of fruit increases dur-

Figure 16.37

Weak, narrow-angled branch attachment.



ing the year, limbs with narrow crotch angles often break or split open.

Minimal pruning favors flower bud formation during the early stages of tree development; consequently, young trees should be pruned only to develop a specific tree form. This is especially true for the olive, an evergreen tree that holds its energy in the leaves. Overpruning olive trees during the first 4 years reduces total tree size and delays fruiting by at least 2 years. Although not as sensitive as olive, severe pruning of deciduous trees must also be avoided to prevent delays in fruiting. Make cuts carefully to achieve the desired shape. Avoid cuts that reduce tree size unnecessarily. For deciduous species, dormant pruning invigorates the buds that remain on the tree and can be very beneficial for developing a few strong scaffold branches in young trees.

Bending branches and shaping trees

The apical bud on fruit tree branches is typically the most dominant. Its dominance is based on its production of growth-regulating hormones that flow downward by gravity and retard the growth of the buds and flowers below. By changing the angle of the branch from vertical to horizontal, the influence of gravity on the flow of growth-inhibiting hormones is moderated or stopped. The greater the angle, the greater the influence, even to the point of branches drooping at an angle greater than 90°. Vertical branches tend to grow vigorous vegetation; horizontal and drooping branches are less vigorous and grow more flower buds. Branches with angles from 45° to 60° are well balanced in both fruitfulness and vegetative vigor. Different species and cultivars respond differently to branch bending, and the rootstock and cultural practices also influence fruitfulness and vegetative vigor.

It is often difficult to direct branch angles, yet most fruit trees will not develop their maximum productive potential with pruning alone. Various devices can hold branches at their desired angle until they become stiff enough to stay there by themselves. Gardeners use small weights, clothespins, props, spreader sticks, electrical tape, and string to bind vertical branches to their desired angle.

Pruning mature, bearing trees

Pruning objectives change as the tree changes from a young, nonbearing tree to a mature tree that has attained full size. In general terms, the pruner must shape the tree to maintain tree health and to allow good sun exposure throughout the tree, permitting optimal photosynthesis that supports high-quality fruit and nut growth. The first branches removed should be any dead, dying, damaged, diseased, or crossing branches that interfere with the desired structure. Additional cuts may need to be made for optimal light penetration. The basic anatomy of a mature tree, including terms used in pruning, is given in figure 16.34.

Prior to pruning any tree, the tree should be evaluated for its vigor. Evaluate the quantity of new wood. The best fruit comes from new wood younger than 5 years old; in some species, fruit comes only from wood that is 1 year old. If the tree lacks vigor, it should be heavily pruned in the dormant period to encourage more vegetative vigor. If a tree is overly vigorous, one option is to avoid pruning it while it is dormant, because dormant pruning tends to invigorate the buds that remain on the tree,

causing even more growth. Instead, bend its branches to wider crotch angles to reduce vigor or prune the tree in the summer (usually May or June) to reduce leaf area and slow growth. Some extremely vigorous trees, such as pear and plum, often require both winter pruning to remove most of the excessively vigorous upright shoots and some summer pruning to reduce height and overall vigor. Most nut trees and olives are not pruned to modify vigor; it is difficult to reduce their size without severely affecting fruit or nut production.

Ideally, maintenance pruning preserves the tree form established in the training process, creates a balance between the growth of renewal wood and fruiting wood, and improves light exposure in the lower portion of the tree. Appropriate tree vigor depends on the fruit tree type, but in general there should be about 12 to 18 inches of new wood on vigorous new shoots. Prune to remove any damaged, diseased, dying, or dead limbs, then thin out both vigorous upright water sprouts and dense branches in the upper portion of the tree that threaten to shade lower areas. For species bearing on 1-year-old wood (e.g., peach, nectarine, and kiwi), remove some or most of the old wood that bore the previous year's fruit, since it is less fruitful than the newer growth. In low-vigor trees with spurs (e.g., apples, pears, plums), the spurs may be shortened for renewal and stiffened to support fruit without bending severely. Leave some weak, short, lateral branches unheaded so that they can develop into spurs for the future. Approximately 20% of the older spur wood should be renewed annually in order to maintain quality fruit production. New spur wood produces fruit for about 5 years.

Proper pruning can help reduce alternate bearing in some tree species (e.g., olive, apple, plum, kiwi). During a heavy bearing ("on") year, trees proceed into dormancy with fewer flower buds due to hormonal signals and competition for nutrients. The smaller crop produced in the off year allows for less competition, greater growth, and more flower bud differentiation for the next on year. To help reduce alternate bearing, prune the trees more heavily in the winter or spring prior to the on year. This helps remove flowers and excess crop, which decreases competition, providing the nutrients needed for increased flower bud differentiation in the following off year.

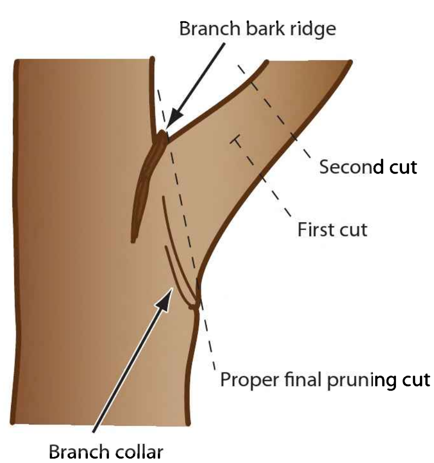


Figure 16.38

Pruning cuts should be made just outside the branch bark ridge (top of cut) and the collar (bottom of cut) so that the bottom of the cut is angled slightly outward. *Source:* After International Society of Arboriculture 1995, p. 3.

Types of pruning cuts

There are two types of pruning cuts: heading and thinning. A heading cut is essentially topping a branch at a point one-third to one-half or more of the distance from the tip to the point of attachment. Heading cuts are made to shorten branches (reduce tree size), invigorate growth, and force lateral branching. If done in the summer, they can help reduce excess vigor and reduce tree height. A thinning cut is made at the base of a branch located in an undesirable position to remove the branch and reduce crowding. Thinning cuts are made to improve light penetration to fruiting wood, maintain tree vigor (less invigorating than heading cuts), and reduce the tree's fruiting potential (excess fruiting). As trees mature, thinning cuts are made more often than heading cuts.

The correct location for thinning cuts is just outside the branch collar (fig. 16.38). A cut at this point develops callus tissue

that fills in the cut surface and leads to rapid wound healing. Thinning cuts should not leave short stubs because they can die back to the base and become entry points for wood-rotting organisms, or they can allow unwanted shoots to grow from dormant buds located at the base of the stub. The cut should also not be made flush with the branch (too close) because it leaves a larger wound.

Long, heavy branches should be removed in three stages to prevent tearing of the bark (see fig. 16.38). First, cut the underside of the branch about one-third of the way into the branch diameter. This cut should be about 20 inches away from where the final cut will be, and the cut should not be too deep. Second, cut the upper side of the branch about 8 inches farther out on the branch from the first cut. The weight of the branch will split the underside of the branch from the second cut to the first. Then, cut the stub that remains at the branch collar, near the base. Research has shown that healing of large wounds is not hastened by covering with tree sealants. The best defense against disease and insect attack is to avoid stubs and not to remove the branch collar. Large wounds can be covered with grafting wax for cosmetic purposes or a fungicide to temporarily prevent the introduction of disease organisms.

Dormant pruning versus summer pruning

The time of year when pruning occurs has a strong impact on shoot growth and fruit development. Dormant pruning is the removal of branches during the winter months; summer pruning is the removal of shoots during mid to late spring or early summer. Both forms of pruning reduce the total bearing capacity of the tree but have distinctly different effects on future tree development.

Dormant pruning is the most invigorating pruning period. Buds that remain have a greater proportion of the reserve carbohydrates stored in the tree and thus grow at a faster rate. This is very beneficial for the development of young trees, where a few strong scaffold branches and rapid growth is desired. It is also important for the development of new wood in mature trees needed for continued fruit production. Dormant pruning can be done from the beginning of leaf fall up to bloom.

Summer pruning is useful to selectively promote the growth of primary and secondary scaffold branches and to remove undesirable competing branches in young trees. This can be done several times throughout the growing season. To eliminate unwanted shoots without affecting tree vigor, remove them before they reach 6 inches long, usually before May. Summer pruning is also done on mature trees for size control and to reduce their vigor. It is a devigorating practice because it removes leaf area, reducing the production of food. Summer pruning (a combination of thinning and heading cuts) is best done between May and July.

Pruning based on bearing habit

Fruit and nut trees should be pruned based on their predominant bearing habit: on spurs, shoots, or both spurs and shoots (see the section “Flowering and Fruiting Habits,” above):

- spurs: apple, pear, cherry, and European plum
- 1-year-old wood: peach, nectarine, fig, persimmon, quince, pecan, olive, kiwi, and walnut
- shoots and spurs: almond, some apples, apricot, plumcot, pluot, aprium, and Japanese plum

Spur-bearing species. Most of the shoots that grew the previous season can be removed during dormant pruning, especially strong, vigorous shoots that grow vertically within the tree and shade the lower spur-bearing branches. Fruit-bearing spurs must be renewed periodically by topping them back when they get too long, usually after 5 to 10 years. They must also have adequate sun exposure to produce large, fully colored fruit. Maintaining adequate sunlight in the lower portion of the canopy often requires thinning of shoots

and branches in the upper canopy. Some spur-bearing species, such as Asian pear, produce excess spurs; these spurs can be thinned to reduce the crop load and the need for excessive hand-thinning, and to instigate more lateral shoot growth that renews old spurs.

One-year-old-wood–bearing species. Peach and nectarine require a volume of shoot growth in order to fruit well the following year; an excess of fruit or lack of pruning leads to poor shoot growth and less crop the following year. Remove all old, weak wood and at least 50% of last year's growth. Pruning in this manner leaves the moderately vigorous lateral shoots to bear and provides positions for shoot growth for the following season. Even with this level of pruning, fruit thinning may still be necessary (see below). Downward-growing branches should be thinned, not headed. Olives, which are very strongly alternate bearing, benefit from pruning every other year during the bloom period. In years of heavy fruit set, prune the trees to thin excess crop and ensure enough shoot growth for the following year. In years of light cropping, little or no pruning is advised. On pecan, some walnuts, fig, persimmon, and pomegranate, a modest amount of pruning ensures terminal growth and the creation of new fruit wood. In winter, prune shoot-bearing species more heavily than spur-bearing species to ensure adequate shoot growth and fruit production.

Figure 16.39

Spreaders and wires used to train an early-bearing apple tree. *Photo:* P. M. Vossen.

Figure 16.40

Suckers growing from the crown and roots. *Photo:* P. M. Vossen.

Shoot- and spur-bearing species. Prune as in spur-bearing species to maintain production on the spurs while retaining some crop on last year's shoot growth.

Summary of basic pruning tips

- Perform initial pruning immediately after planting a new bare-root fruit tree, as shown in figure 16.34 and discussed in the section "Planting Bare-Root Trees." Top the trees at 20 to 24 inches in order to balance the top with the root system that was cut off at the nursery and to encourage low branching. Cut back any existing branches below that to two buds.
- Prune most temperate fruit trees during the dormant season, when the leaves are off the tree. It is easier to see what you are doing, and removal of dormant buds (growing points) invigorates the remaining buds. Conduct summer pruning, which is usually done from May to July, to manage overly vigorous trees or trees that are too large. Summer pruning may

slow fruit ripening and expose some fruit to sunburn.

For the first few years, prune young trees to encourage structural strength and rapid growth until they fill their allotted space. Leave most of the small, horizontal branches untouched for later fruiting. Place spreaders or weights in the tree to encourage proper tree form (fig. 16.39). For vase-trained trees, the main scaffolds should be attached at angles of about 45° to 60° to the trunk and evenly spaced around the trunk. For central leader trees, the lower branches should be attached at angles of about 45° to 60° to the trunk. Higher branches should be attached at angles of 60° to 90°. Always remove suckers growing from the crown or rootstock (fig. 16.40).

Evaluate the vegetative vigor of the tree to be pruned. If excessive, prune very lightly in the winter or do not prune at all; consider summer pruning to reduce vigor. If vigor is lacking, prune the tree heavily to stimulate growth in the remaining buds. Balanced trees should have about 12 to 18 inches of shoot growth throughout the tree.

When deciding which branch to cut and where to cut it, remember that topping a vertical branch encourages vegetative growth, branching, and excessive shading of lower branches. Thinning cuts that remove entire branches open the tree to more sunlight. Head horizontal branches to renew fruiting wood and thin excessive fruit. Horizontal shoots left uncut bear earlier and heavier crops.

In general, upright branches remain vegetative and vigorous, whereas horizontal branches are more fruitful. A good combination of the two is necessary for fruiting now and in future years. Remove suckers, water sprouts, and most competing branches growing straight up into the tree. Downward-bending branches bear fruit early but eventually lose vigor; cut off the part hanging down.

Make clean cuts within ¼ inch of a bud. Do not leave stubs. The response to pruning is localized: new growth is stimulated only within 6 to 8 inches of the cut. The more buds that are cut off, the more vigorous the new shoots will be.

Do most of the pruning in the top of the tree so that the lower branches are exposed to sunlight. Sun-exposed wood remains fruitful and produces the best fruit. Excessive shade in the lower portion of the canopy results in loss of fruitwood, requiring severe heading cuts to stimulate new growth.

Adjust the pruning level to tree vigor. Weak trees require heavier dormant pruning to renew vigor. For peach, nectarine, and kiwi, remove about 50% of last year's growth. For apple, pear, plum, apricot, olive, walnut, pecan, chestnut, persimmon, pomegranate, and fig trees, remove about 20% of last year's growth.

Figure 16.41

Fruit thinning in peach. Same branch before (left) and after (right) thinning.
Source: After LaRue and Johnson 1989, pp. 58, 59.

Fruit Thinning

Removal of flowers or immature fruit early in the spring can increase fruit size by limiting the number of fruit that continue growing. Thinning also increases the leaf-to-fruit ratio and removes smaller

Figure 16.42

Thin most fruits to about 4 to 8 inches apart. *Photo:* P. M. Vossen.

fruit that would not reach optimal size or quality. Apple, European and Asian pear, apricot, peach, plum, kiwifruit, table olives, and persimmon are almost always thinned until the leaf-to-fruit ratio is favorable for supporting the growth of adequately sized fruit (fig. 16.41). Nut crops and cherries are typically not thinned. Standard apple, peach, and nectarine cultivars require a leaf-to-fruit ratio between 40:1 and 75:1 (40–75 leaves per fruit) to reach a good size at harvest. Early cultivars need a larger ratio. Spur-type apple cultivars and genetic dwarf trees require a smaller leaf-to-fruit ratio of 25:1. This seems to be related to the fact that photosynthates and stored food reserves are distributed more to fruit growth than vegetative growth in spur-type trees. Plums and apricots need a leaf-to-fruit ratio of 30 to 50 leaves per fruit because of their smaller size, and cherries and olives need an even lower ratio because they are very small fruit in comparison.

Large fruit grow from flower buds that developed in full sunlight on trees that have a favorable leaf-to-fruit ratio. Proper dormant pruning followed by hand-thinning creates fruit that attain a good size and encourages a good number of flower buds for the next year. Fruit on trees that are not thinned are edible but are usually smaller. Excess fruit can also break branches.

The earlier that fruit are thinned and the leaf-to-fruit ratio is increased, the larger the fruit will be at harvest and the greater the effect on next year's bloom. The home fruit gardener should use judgment regarding spacing of the fruit and removing small and damaged fruit. Spacing fruit every 4 to 8 inches evenly along a branch (fig. 16.42) or leaving only one fruit per spur is a good practice, but it is more important to leave the largest fruit, even if the spacing is slightly irregular. Adjust the number of fruit to branch vigor, leaving fewer fruit on smaller limbs. Most home fruit producers do not thin enough fruit; it usually takes 2 or 3 years of harvesting small fruit from inadequate thinning to learn to thin the fruit properly.

Blossom thinning can increase the leaf-to-fruit ratio, since competition between potential fruit and elongating shoots and roots is relieved early; however, there is the risk of overthinning if bad weather during or after bloom reduces fruit set.

Irrigation

Fruit and nut trees grow best if irrigated regularly. Drought stress reduces fruit size and shoot growth, especially in young trees. One of the first things that happens when fruit trees are water stressed is that the leaf pores (stomata) close to conserve internal water. In so doing, the exchange of gases is reduced, which limits the supply of carbon dioxide for photosynthesis. If the tree is severely water stressed, the leaves wilt, curl, and sunburn; the fruit also grow smaller, lose water, shrivel, and sunburn. Good irrigation practices supply water at sufficient intervals to prevent plant stress. This ensures maximum plant growth, fruit size, and yield. In some circumstances, however, a slight water stress induced at specific growth stages can improve fruit flavor, enhance sugar or oil content, and limit vegetative growth. This is known as regulated deficit irrigation (RDI).

Table 16.4.

WATER MANAGEMENT GUIDE FOR TEMPERATE FRUIT TREES

	Daily water use (gal/day)			
Tree age (size)	Cool, early spring or late fall, foggy 0.10 in/day	Warm, spring or fall, some fog 0.20 in/day	Hot, midsummer, windy, no fog 0.25 in/day	Very hot (100°F), midsummer 0.30 in/day
1 sq ft	0.062	0.125	0.156	0.187
1 year old (4 sq ft)	0.25	0.50	0.62	0.75
2 years old (10 sq ft)	0.62	1.25	1.56	1.87
3 years old (36 sq ft)	2.25	4.5	5.61	6.73
4 years old (100 sq ft), semidwarf, mature	6.20	12.5	15.6	18.7
large standard mature tree (300 sq ft)	18.6	37.5	46.8	56.1
1 acre solid cover (43,560 sq ft)	2,715	5,431	6,788	8,146

Water quality may be an issue in parts of California where water has excess salt or mineral content. If a problem is expected, test the irrigation water for its mineral content to avoid toxicity to trees.

The amount of water evaporating from the soil surface plus the water used (transpired) by the tree is called crop evapotranspiration (ETc). The amount of water a fruit tree uses depends primarily on how big it is and how hot the day is. Several other factors also influence water use, such as relative humidity and wind, but they are less important. Table 16.4 is a water management guide for temperate fruit trees based on crop evapotranspiration rates and tree size. Since the summer days in the main fruit-growing regions of California are predictably sunny and warm, use this chart to determine the water use requirements for fruit trees. In the spring and fall when the days are shorter and cooler, the trees need less water.

Water use by fruit trees is very similar between species. The greatest difference in water use is due to tree size. For example, table 16.4 shows that a tree that occupies 36 square feet (6 ft by 6 ft) uses 5.6 gallons of water per day; a tree that is about three times as large, 100 square feet (10 ft by 10 ft), uses almost three times as much water (15.6 gal/day). This is based on a typical hot midsummer day using ¼ inch of water per day.

Water use for a medium-sized semidwarf fruit tree is about 16 gallons of water per day (0.25 in/day) on a hot summer day on the coast of California without any fog influence. That same tree in the Central Valley would use about 19 gallons of water per day (0.3 in/day). A tree in the Central Valley equipped with two 1-gallon-per-hour drip emitters would have to be irrigated about 9 to 10 hours every day to supply the needed water. The tree on the coast would be irrigated for 7 to 8 hours every day. Olive trees are an exception because of their inherent drought tolerance and small fruit size, though table olives require more water than oil olives to produce large fruit. Mature olives for oil can be deficit irrigated to receive about half the amount of water of other fruit trees, but young olive trees should be fully irrigated in order to encourage more shoot growth without stunting tree size.

Drip irrigation

Unlike basin or sprinkler irrigation, drip irrigation does not use the soil as a reservoir for water; it supplies the tree's water requirements as needed on a daily basis. Drip irrigation wets only a small area, limiting weed growth, and it is easily adapted

to many landscape situations. Although a small area is wetted under drip emitters, the root density increases in this zone to ensure adequate water uptake. Soil type or depth has very little influence on drip-irrigated trees, since the water use rate is determined by weather and tree size. Soil water-holding capacity is also unimportant due to daily irrigations. Drip irrigation should begin in early spring before much soil moisture has been used because this stored water may be needed later in case the drip system is accidentally shut down. Only 10 to 20% of the rooting area must be wetted for good tree performance. Below are two examples that show how long to drip-irrigate trees in various conditions.

Example 1

A young semidwarf fruit tree, 2 years old, occupies a space of 10 square feet. It has two 1 gal/hr emitters, and on a warm spring day the water use rate is about 0.2 in/day.

How much to water: Table 16.4 shows that the tree requires 1.25 gal/day.

How often to water: 1.25 gal/day ÷ 2 emitters = 37.5 min/day, or 75 min (1 hr 15 min) every other day.

Example 2

A mature, large, standard-sized fruit tree occupying an area of 300 square feet has four 1 gal/hr emitters. On a hot summer day, the water use rate is about 0.25 in/day.

How much to water: Table 16.4 shows that the tree requires 46.8 gal/day.

How often to water: 46.8 gal/day ÷ 4 emitters = 11.7 hr/day, or 23.4 hr every other day.

Sprinkler irrigation

Sprinkler-irrigated trees use the same amount of water as drip-irrigated trees plus an additional 20% for loss due to evaporation and the nonuniformity of application. Sprinklers apply more water at once, and some water is stored in the soil before the next irrigation. A larger area is also watered than with drip irrigation, and weed growth also covers a greater area.

Another important difference between drip- and sprinkler-irrigated trees is that the soil rooting depth and the soil water-holding capacity, which is based on soil type (sand, clay, or loam), are important since water must be stored in the soil. The capacity for the soil to hold water is based on the size of the mineral and organic matter particles in the soil. Most soil holds about 2 inches of available water per foot (in/ft) of rooting depth:

sandy soil: 1 to 1½ in/ft

loamy soil: 1½ to 2½ in/ft

clay soil: 2½ to 3½ in/ft

Because sprinkler-irrigated trees are irrigated only periodically, the trees deplete the water stored in the soil over a period of several days. Eventually, the trees can become water stressed as the water in the soil is used up. To prevent significant water stress, the amount of stored water should never be allowed to become completely depleted. Most fruit tree growers use a figure of 50 to 75% allowable depletion before irrigating to prevent water stress to the trees.

Both overirrigation and underirrigation have a negative effect on tree performance. If trees are overirrigated, the water that sinks below the root zone is wasted; overirrigation can also encourage weeds, pests, and diseases. Underirrigation, which is caused by too long an interval between watering or an insufficient quantity of water per irrigation, can lead to water stress. Care should be taken to apply the proper amount of water at the proper time (see the example below).

Example. A mature, large, standard-sized fruit tree occupies an area of 300 square feet. The rooting depth is 3 feet in loam, the water-holding capacity of loam is about 2 in/ft, the daily water use (ET) is 0.25 in/day in July, the allowable depletion is 75%, and the irrigation efficiency loss is 20%.

How much to water:

Water-holding capacity = 3 ft × 2 in/ft = 6 in

Allowable depletion = 6 in × 75% = 4.5 in

Volume of water to apply =
4.5 in + 20% = 5.4 in

How long to water: Set open containers under the sprinklers and measure how

long it takes to apply 1 inch of water. Multiply the duration times 5.4 inches of water to get the total amount of time needed. If a sprinkler applies 0.3 inch of water per hour, it would take 18 hours to apply 5.4 inches of water.

How often to water: 5.4 inches water ÷ 0.25 inches water use/day = about once every 21 days.

Sprinklers irrigate various areas and patterns. Large areas may require impact sprinklers, which have high application rates. Plastic minisprinklers, small sprinklers attached to drip tubing, are usually sufficient in the home garden. Their water application rates are also easily accommodated by city water systems. Each minisprinkler usually delivers about 10 to 20 gallons per hour, or 10 times the average drip emitter. A minisprinkler system is typically run two or three times per week, with some water held in the soil in storage. Run times can be calculated from the daily water use table (see table 16.4), multiplied by the number of days between irrigation intervals. Care must be taken to investigate the depth that the irrigation water is reaching when supplied by minisprinklers. Some emit fine streams that wet an area up to 15 feet in diameter; they require an excessive amount of time to wet soil to a depth of 24 inches.

Most fruit tree roots are located from 6 to 36 inches deep in the soil. This topsoil area contains most of the nutrients and oxygen. Irrigation should focus on maintaining adequate moisture in this zone. Contrary to belief, roots do not seek moisture but grow where moisture is present. Home orchard trees that are on deep soil can get by with less intensive irrigation because the tree roots are deeper, providing a buffering capacity for drought stress. Shallow soil must be managed much more intensively, with lighter, more frequent irrigations.

It is very difficult to determine how much water fruit trees are getting if they are watered by hand with a garden hose. The soil moisture should be checked with a small trowel or shovel down to a depth of at least 1 foot on the day after watering to determine whether the soil moisture is adequate.

Fertilization

Successful fruit production requires that trees have an adequate supply of essential nutrients. The primary nutrient that home gardeners need to supply on a regular basis is nitrogen (N). Potassium (K) is the second-most-common deficiency in tree crops, because many of the soils of California are somewhat deficient. Phosphorus (P) deficiency is very rare in tree fruits and nuts. In some instances, zinc (Zn), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), calcium (Ca), boron (B), or molybdenum (Mo) may be deficient or in excess. The symptoms of many of these micronutrient problems are very difficult to identify properly. One solution to suspected deficiencies is to apply compost, since it contains small quantities of most of the nutrients. As the organic material decomposes, it slowly releases these basic minerals into the soil for the trees to take up. This is often less complicated than trying to find the exact micronutrient missing, but the release of nutrients is slow and may take a long time to correct a deficiency.

Many conditions can limit a fruit or nut tree's ability to take up the proper quantity of nutrients even when an adequate quantity of the nutrients is present in the soil. Cold or wet soil can limit root growth and activity to the point that some nutrient deficiency symptoms become visible; extremely dry soil may cause a similar situation. These are usually temporary conditions that are corrected when the soil warms up or is properly irrigated. In severe cases, tree roots or crown areas become partially rotten and unable to pick up soil nutrients. Adding additional fertilizers to control the visual symptoms of nutrient deficiency when the roots are rotten is useless. Also, some plant viruses, herbicides, or other pesticides can cause symptoms that can be confused with

nutritional problems. Always identify the correct cause of the problem, if possible.

The bibliography at the end of this chapter lists several comprehensive University of California publications about the fruits and nuts discussed in this chapter. These publications include color photographs of deficiency symptoms and extensive discussions about fertilization practices. While many of these publications are written for commercial growers, the fertilization principles, photographs, and issues discussed are valuable for the home gardener as well. To properly identify a specific plant nutrient deficiency, UC farm advisors use both visual symptoms and laboratory analysis of tissue samples from the tree in question.

Fertilization in the prebearing years

In the prebearing years, fruit and nut trees should be fertilized to encourage maximum early growth. Neither commercial fertilizer nor manure should be put in the planting hole when planting temperate fruit and nut trees because either may burn the roots. Zinc and nitrogen deficiency are fairly common in the early growing years. For most soil, fertilizer is needed during the first growing season, but the fertilizer should not be applied until early summer, when there is 6 to 8 inches of new growth. Then apply about 2 ounces of a nitrogen-containing fertilizer such as ammonium sulfate (21-0-0) or 16-16-16, or 1 ounce of urea (46-0-0), or 2 pounds of compost once a month until leaf fall. To add zinc, apply 1 to 2 ounces of zinc sulfate per tree to the soil once per year. Either scatter the fertilizer on the soil under the tree, keeping it at least 1 foot from the trunk, then water it in, or place it directly under drip emitters if drip irrigation is used. If nitrogen fertilizers lie on the soil surface without being watered into the soil, some of the nitrogen value can be lost into the air by volatilization. The same is true for compost, but to a lesser degree because it releases its nutrients more slowly.

The second year, apply approximately twice the first-year rate. In subsequent years, the rate should increase proportionately with the size of the trees. Keep the trees well fertilized, especially with nitrogen, so that they grow rapidly to fill their allotted space. Once the trees enter the flowering and bearing years, the fertilizer rates should be reduced (see below).

Fertilization of mature, bearing trees

Nitrogen status can have a profound effect on the vigor of fruit and nut trees. It is one of the ways to manage shoot growth and influence fruit set and bearing. Lower nitrogen levels lead to less vigor and shorter shoot growth, which may be perfect for apples or pears but not enough for peaches or walnuts. Limiting nitrogen often enhances fruit set, improves fruit color, and advances the fruit maturity date. It also reduces shoot growth, which leads to better light penetration and less need for pruning, and may also help limit the size of overgrown trees. Fully bearing, average-size mature trees in the home orchard should be fertilized at the rates and times stated in table 16.5.

Nitrogen

Nitrogen (N) deficiency appears as a general light green color or yellowing of the leaves, generally on the older leaves first; in peaches and nectarines, the leaves also appear reddish on the margins. Trees with a very low nitrogen level have stunted growth, poor fruit set, and smaller fruit size than do trees with higher levels of nitrogen.

There is no blanket rate of nitrogen fertilization recommended for all tree types listed in table 16.5; the rates vary from 1 to 2 pounds of actual nitrogen per tree per year (N/tree/year), depending on the tree type and size. Often, the nitrogen fertilizer program recommended for mature trees is divided into two applications, the first in the spring just prior to bud break and the second in late summer while trees can actively take it up. To determine how to calculate the amount of a given fertilizer product needed to deliver the recom-

mended rates, see the discussion of fertilizers in chapter 3, “Soil and Fertilizer Management.”

When selecting a fertilizer, take into consideration extremes in soil pH. Soil with low acidity (high pH, above 7.5) should be fertilized with a fertilizer that will gradually reduce the soil pH, such as ammonium sulfate, ammonium nitrate, or urea. For soil with high acidity (low pH, below 5.5), use a neutral fertilizer such as calcium nitrate. Check the list of ingredients on fertilizer bags for the original source of the form of nitrogen. The source of the nitrogen makes very little difference to the tree. Most plants take up nitrogen primarily in the form of nitrate (NO_3^-), and some take it up in the form of ammonium (NH_4^+). The ammonium forms of fertilizers are gradually broken down into nitrate in the soil. Even organic fertilizers made up of nitrogen-containing proteins and amino acids eventually break down into the nitrate form for plant uptake.

When considering how much nitrogen to use, more is not necessarily better. Excessive nitrogen fertilization overinvigorates vegetative growth on bearing trees, which reduces light penetration into the canopy and results in reduced flower bud formation and reduced fruit yield. Provide enough nitrogen to maintain healthy nutritional status but not enough to oversupply nitrogen. Excess application may also stimulate weed growth and pollute surface water and groundwater resources.

Phosphorus

Phosphorus (P) deficiency in fruit or nut trees in California is extremely rare. There is apparently enough phosphorus in the soil, and it is readily available to the trees. In some cases where there has been land excavation or very poor soil, a preplant application of phosphorus in the soil might be necessary, and phosphorus could also be applied in a complete fertilizer on a regular basis. In most cases, however, applying phosphorus is a waste of money and resources.

Potassium

Potassium (K) deficiencies are sometimes found in peach, plum, nectarine, and kiwifruit in the San Joaquin and Sacramento Valleys, and elsewhere on sandy soil. When potassium is deficient, leaves turn pale greenish yellow and tend to curl inward (boating) and burn along the margins and tips, generally on the older leaves first. Poor fruit size is commonly associated with low potassium. Because potassium is required in large amounts by fruit and nut trees, deficiency symptoms may be induced when there are other problems in the root zone, such as root diseases, drought, or excess water. If potassium deficiency does occur, one treatment usually corrects the problem for several years. A fall application of potassium sulfate at a rate of 5 to 10 pounds per tree in sandy soil and 15 pounds per tree in finer-textured soil should be sufficient to correct deficiency symptoms for 3 to 5 years. Compost contains potassium, and if used on a regular basis it should prevent any deficiency except in very sandy soil. Potassium does not move very well in soil, so it should be worked into the root zone at least 6 to 8 inches deep or placed in a higher concentration just under drip emitters.

Calcium (Ca)

Calcium (Ca) deficiency is very rare in California and usually occurs only on serpentine soils that are very high in magnesium. Severe calcium deficiency may cause twig dieback, leaf drop, and chlorotic patches on leaves. Bitter pit in apples and pears can be more severe when levels of soil calcium are low. Calcium deficiency can be easily corrected in acid soil (pH below 6.0) with the addition of agricultural lime, dolomitic lime, or oyster shell flour at a rate of 5 to 10 pounds per tree. When soil pH is above 6.0, calcium deficiency can be corrected by adding gypsum at a rate of 3 to 5 pounds per tree. Compost also contains small amounts of calcium, so regular additions of compost will work. Calcium-containing materials should be tilled into

Table 16.5.

CALENDAR OF HOME GARDENING OPERATIONS FOR SELECTED TEMPERATE FRUIT AND NUT TREES

almond	Prune trees in Dec/Jan to allow more light into tree and promote growth of new fruiting wood. Remove dead, diseased, drooping branches and suckers in center of tree. Remove and destroy all old nuts on trees and on ground to reduce overwintering navel orangeworms. Spray trees with dormant oil to kill peach twig borer, San Jose scale, and mite eggs.	Just prior to first irrigation, fertilize mature trees with 1 lb urea or 50 lb of compost and water it in. Young trees: use small, frequent doses of N throughout the growing season. Drip-irrigate daily to meet tree needs. Sprinkler-irrigate every 1 or 3 weeks starting 2 to 3 weeks after winter rains. Apply 2 to 3 in of water per irrigation. Trees growing in shallow or sandy soils need more frequent watering.	Continue irrigating as during spring bloom season. Fertilize trees again at same rate as in spring, just prior to last irrigation before harvest. Water in.	Nuts are ready for harvest after hulls split and shell is dry and brown. Separate hulls from nut and discard. Nuts can be in shell or out. Freeze in-shell nuts for 1–2 weeks to kill resident worms. Store in plastic bags to prevent reinfestation. Spray trees with fixed copper during or after leaf fall but before onset of winter rains to reduce damage from shot hole fungus the following spring.
apple	Spray trees with dormant oil to control San Jose scale, aphid eggs, mite eggs. Prune 15 to 20% of last year's growth to let light in. Remove diseased or broken limbs.	Spray trees with a fungicide to control apple scab and powdery mildew at green tip stage, pink bud stage, and at 10-day intervals thereafter until rain stops. Thin apples by hand within 30–69 days after full bloom to about 1 apple per 6 in of shoot growth. Fertilize prior to first irrigation. Mature trees, use 1 lb urea or 50 lb compost spread on the surface.	Fertilize young irrigated trees monthly (through Jul). Use 8 oz urea or 20 lb compost per tree. Water in. Do not exceed 1 oz urea per emitter per application. Spray (May 1–Sep 1) to control codling moth worms; time sprays to visual ID of worm holes in fruit. Control aphids if damage exceeds 50% of leaves crinkled and aphids present. Control mites if damage is severe. Drip-irrigate daily or sprinkler-irrigate every 2–3 weeks.	Continue irrigating; fertilize mature trees after harvest. Repeat rates from summer. At leaf fall, remove and destroy or compost leaves to prevent the spread of apple scab. Control weeds throughout the season with an organic mulch. Harvest from Jul–Nov, depending on fruit taste.
apricot	Spray trees with dormant oil to control San Jose scale, aphid eggs, mite eggs, and peach twig borer. Do not use sulfur on apricots; use fixed copper.	Spray to control brown rot and shot hole fungus as blooms start to open. Sprays may be required at 10- to 14-day intervals if weather is rainy. Drip-irrigate daily or sprinkler-irrigate every 2–3 weeks. Fertilize before first irrigation with 1 lb urea or 50 lb compost. Water in. Thin fruits to about 4 to 6 in apart when 1/2 to 5/8 in in diameter. Paint trunks with 50:50 mix of white interior latex paint and water to prevent sunburn and borer infestation.	Continue same irrigation schedule as in spring. Fertilize young trees monthly (through Aug) at one-quarter spring rates to encourage vigorous growth.	Prune trees before onset of winter rains to prevent *Eutypa* fungus infection of pruning wounds. Remove about 20% of last year's growth to let light into tree. Remove old, broken, or diseased branches. Spray trees during or after leaf fall but before onset of winter rains to control shot hole fungus. Do not use sulfur on apricots; use fixed copper. Harvest when fruit begin to turn soft.
cherry	Spray with dormant oil to control San Jose scale. Prune 10% of last year's growth on mature trees to let light in. Remove broken or diseased branches. Cherries may do better against bacterial canker (gummosis) if treated with fixed copper spray.	Apply fungicide to control brown rot at popcorn and full bloom stages. Fertilize nonirrigated mature trees just before or during a rain with about 1 lb urea or 50 lb compost. Fertilize irrigated trees just before an irrigation.	Cover trees with bird netting to control birds. Drip-irrigate daily with amount equal to size of tree (see table 16.4). Sprinkler-irrigate about every 2–3 weeks with 3–5 in water per irrigation, depending on soil depth and water use. After harvest, fertilize mature trees with 2 lb urea and water in immediately.	Irrigate to maintain good tree vigor through summer heat and into fall until winter rain takes over. Drip-irrigate daily to match daily use. Sprinkler-irrigate every 3–4 weeks to wet all soil in root zone but stop Sep 1 to prevent root rot. Harvest when fruit is soft and sweet.
olive	Spray with fixed copper to prevent peacock spot, especially in wet years. For oil cultivars apply just after harvest.	Prune trees during the bloom period. To reduce alternate bearing, remove more shoots from trees with heavy bloom and skip trees with light bloom. Fertilize mature trees with 1 lb urea or 50 lb of compost. Begin irrigating trees so there is no water stress during bloom.	Control weeds with organic mulch or cultivation, especially on young trees. Fertilize young trees with 1 oz of urea under each drip emitter every month and irrigate in. For sprinkler-irrigation, fertilize with 1/2 lb of urea just prior to an irrigation. Apply drip irrigation every day according to water-use requirements.	For table fruit, harvest when fruit is still green, just before the straw yellow stage. For oil, harvest when the fruit has turned yellow to reddish purple on the outside, but the flesh is still green-yellow. Continue irrigation right up to harvest if weather is dry; do not allow fruit to shrivel. Apply fixed copper to prevent peacock spot before first major fall rains. Wash copper off fruit prior to processing or apply after harvest.

Table 16.5. cont.

CALENDAR OF HOME GARDENING OPERATIONS FOR SELECTED TEMPERATE FRUIT AND NUT TREES

peach and nectarine	Spray trees with dormant oil to control San Jose scale. Spray fixed copper to control peach leaf curl Dec 1 and Feb 1. Prune 50% of last year's wood to thin the crop and ensure good shoot growth and fruiting potential for future years.	Apply fungicide during bloom to prevent brown rot, which may require 1 to 3 sprays, depending on weather. Rainy periods require more spray. Fertilize young trees monthly with high-N fertilizer beginning Mar 1. Use 1/2 lb urea or 25 lb compost per tree per application. Mature trees need 50% more. Water fertilizer in. For drip irrigation, use 1 oz of material applied under emitters every month. Do not exceed 1 oz urea per emitter per month. Thin fruit to about 6 in apart when marble sized. Thinning reduces number of fruit, increases size, and prevents limb breakage.	Fertilize young trees monthly (through Aug). Use 1/2 lb urea or 25 lb compost per tree per application. Mature trees need 50% more. Water fertilizer in. Do not exceed 1 oz urea per emitter per month. Drip-irrigate daily or sprinkler-irrigate about every 3 weeks. Maintain a weed-free area around the base of the trees within 3 ft of the trunk with an organic mulch 3 to 4 in deep.	Spray fixed copper for shot hole fungus in Nov before first heavy rain. Harvest as fruit turn soft but before they fall from the tree. Fertilize and irrigate just after harvest. Remove mummies from tree.
pear	Spray trees with dormant oil to control San Jose scale, aphid eggs, mite eggs, and overwintering adult pear psylla. Prune 20% of last year's growth to let light in. Remove diseased (fire blighted) and broken limbs.	Spray trees with a fungicide to control pear scab at green tip stage, full bloom, and at 10-day intervals until rain stops. Thin pears to 6 in apart if crop is heavy. Fertilize prior to first irrigation. Apply 1 lb urea or 50 lb compost.	Fertilize young trees monthly (through Jul) using one-half spring rates. Spray monthly (May 1–Aug 1) to control codling moth worms. Time sprays to visual ID of worm holes in fruit. Control aphids if damage exceeds 50% of leaves crinkled and aphids present. Drip-irrigate daily or sprinkler-irrigate every 2–3 weeks.	Using spring rates, fertilize and irrigate mature trees right after harvest. Clean up fallen fruit to reduce codling moth. Harvest as fruit soften and by flavor. At leaf fall, remove and destroy or compost leaves to prevent the spread of apple scab.
pistachio	Remove broken or dead shoots. Head back shoots to force lateral growth leaving 2–3 vegetative buds at the tip of each branch. Spray with dormant oil if scale is a problem. Clean up all old nuts on the ground or in the tree.	Prune out blighted shoots. Keep the trees weed free. Begin irrigation so there is no water stress during bloom but avoid excessive wetness. Spray trees with a zinc and boron foliar spray.	Keep the trees well irrigated so the soil is always moist but not too wet. Drip irrigate daily or sprinkler-irrigate every 2–3 weeks to water deeply into the soil. Keep the water off the foliage to minimize foliar disease. Apply 1 lb of ammonium sulfate in five applications over the summer months or apply 20 to 25 lb. of compost or manure to each tree.	Harvest nuts early as they mature to avoid worm damage. Knock or shake nuts down onto tarps. Hull the nuts immediately to avoid shell staining using a coarse surface. Then dry the nuts in a well-ventilated area at 75° to 85°F. Freeze the nuts for a few days To kill any insects present. Store dried nuts in the refrigerator if possible. Remove and destroy any blank or rotten nuts on the ground or in the tree.
plum and prune	Spray trees with dormant oil to control San Jose scale, aphid eggs, mite eggs. Prune 20% of last year's growth to let light in. Remove diseased or broken limbs.	Spray trees with a fungicide to control brown rot as blossoms appear. 2 or 3 sprays may be needed if weather is rainy, cloudy. Fertilize mature trees with 1 lb urea or 50 lb compost per tree. Irrigate about every 2–3 weeks or drip-irrigate every day. Fertilize trees just prior to irrigation. Use lower rates for vigorous trees. Thin fruit to about 4–6 in apart. If larger fruit is desired, leave fewer fruit. Control aphids if severe damage (50% of leaves curled and aphids present).	Fertilize young trees monthly (through Aug). Use 4–8 oz urea or 10–20 lb compost per application. Water in. Do not exceed 1 oz urea per emitter per application. Drip-irrigate daily or sprinkler-irrigate about every 2–3 weeks. Use organic mulch to maintain a weed-free area within 3 ft of the tree.	Fertilize and irrigate trees just after harvest with 1–2 lb urea or 20–40 lb compost per mature tree. At leaf fall or before major rains, spray fixed copper to prevent shot hole fungus.
walnut	Prune trees by thinning out crowded areas to let light into tree. Remove broken or dead branches. Spray trees with dormant oil to control scale insects, if needed.	Spray for blossom blight when female flowers appear (tiny nuts with feathery pistil) and at 7-day intervals until rainy weather stops. Blight appears as black blossom ends of nuts in June and later as black hollow nuts. Remove all weeds from tree base to reduce competition and pest problems. Fertilize mature trees with 5 lb urea or 250 lb compost.	Keep tree base dry to reduce crown rot problems. Irrigate trees at the drip line but away from trunks. Sprinkler-irrigate with about 3 in water every 3–4 weeks or drip-irrigate daily during May–Oct. Young, small trees need 4–12 gal water per day; large trees about 20–40 gal per day. Spray for walnut husk fly about Aug 1 and Aug 15. Damage is cosmetic, control is optional. Spray to control codling moth worms or tolerate damage.	Harvest nuts by shaking or poling the tree when green hulls begin to break away from the shell. Nuts are fully mature at this stage. If left on the tree or allowed to fall on their own, the hulls will rot and stick to the shell. Hull nuts, then freeze in-shell nuts to kill resident worms. Store in plastic.

the soil 6 to 8 inches deep. Bitter pit in apples and pears can be somewhat corrected with regular irrigation and lowering nitrogen fertilization rates, which moderates shoot growth so that more calcium moves into the fruit.

Magnesium (Mg)

Magnesium (Mg) deficiency appears as marginal chlorosis on the leaves in an inverted V-shaped pattern. It mostly affects basal leaves of the shoot; terminal leaves are not affected. It usually occurs in soil with a very high level of potassium and with young trees. To correct this problem the trees can be sprayed or ground-treated with small quantities of Epsom salt (magnesium sulfate).

Zinc

Zinc (Zn) deficiency is a common nutrient deficiency in tree crops in California. Zinc deficiency causes mottleleaf—small terminal leaves with yellow mottling between the large leaf veins. Leaves near the growing tips are small, narrow, and bunched together. In the spring, shoots take on a yellowish cast, and mottleleaf is quite evident. Dieback of twigs may occur in severe zinc deficiency. Zinc-deficient trees may have poor and/or delayed bloom and small, low-quality fruit.

Foliar sprays and chelated formulations are available to combat zinc deficiency. Application timing depends on the fruit or nut tree in question. An early- to mid-November application of zinc sulfate is recommended for almond, apple, apricot, cherry, pear, plum, and prune. Leaf burn and defoliation may occur as a result of this spray, but it is not detrimental at this time of year. The dormant zinc spray should not be made at the same time as a dormant oil spray. Use 1 to 2 ounces of zinc sulfate (36% metallic Zn) in 1 gallon of water. To correct for zinc deficiency in peach and nectarine in the home orchard, an application in April of ⅔ ounce basic zinc sulfate (52% metallic Zn) is recommended; on walnut, a spring application is recommended. During the growing season, basic (neutral) zinc, or chelated zinc, sprays can be applied without leaf burn. Liberal applications of compost applied to the soil surface under the trees will eventually correct the problem, but depending on the severity of the deficiency, this may take several years. Fertilizers high in phosphorus, such as poultry manure, bind zinc and render it less available to the tree.

Iron

Leaves deficient in iron (Fe) are quite striking. Bleached yellow to white leaves with green veins is the symptom most often seen, generally on the younger leaves first. Leaf size is usually normal. The fruit tend to ripen early and the fruit quality is normal. If the tree is severely deficient, causing shoot dieback and poor growth, production and fruit quality are reduced. Iron deficiency, or chlorosis, is usually caused by alkaline soil (high pH, above 8.0) or very wet soil. Iron deficiency can be caused by overwatering: the lack of oxygen that results from the excess water inhibits root function and iron absorption by plants. It may also be caused by high lime content in the soil (lime-induced chlorosis).

Adding only iron to soil seldom corrects iron deficiency symptoms. Correcting (acidifying, or lowering) the soil pH is the most important thing to do. This is best accomplished by adding sulfur to the soil around the tree. In most cases only a small portion of the soil profile under the tree must be modified in order to get a response in the tree. Usually, filling a few 2-inch-diameter holes or a narrow trench around the tree with soil sulfur is effective.

In some cases, symptoms of iron deficiency can be corrected by adjustments in irrigation. Several foliar sprays containing iron may partially combat iron chlorosis. Wetting agents should be added to the spray to promote good coverage, and several sprays of dilute solution may be preferable to one spray at full concentration. If deficiency symptoms occur on pears, add ½ pound of iron chelate to the soil during nitrogen fertilization in the spring. While the chelated iron may cor-

rect many cases of leaf yellowing related to iron deficiency, chelated iron is very acidic and should be used with caution because it can cause leaf burn. Soil-applied iron slurries are longer lasting than foliar chelate sprays.

Boron

Excess boron (B) can be a problem on the western side of the San Joaquin Valley and in isolated geothermal areas. Peach and nectarine, two of the most sensitive crops to boron toxicity, exhibit small necrotic spots on the underside of the midrib; cankers along the midrib, on petioles, and on young twigs; leaf yellowing, defoliation, twig dieback, and gumming in severe cases; and distorted fruit. This condition is corrected by leaching the boron out of the root zone. If you suspect boron toxicity, test the irrigation water; the boron level in it should not be above 2 to 5 ppm. Apply additional nitrogen fertilizer as calcium nitrate may help alleviate boron toxicity.

Boron deficiency can occur in some soils in California and may be related to low boron levels in water. Deficiency symptoms include shoot tip dieback, blossom blast, and misshapen fruit. Boron deficiency is corrected by a single application of ¼ to ½ pound of boric acid (H_3BO_3) or borax ($Na_2B_4O_7 \cdot 10H_2O$) per tree.

Manganese

Deficiency of manganese (Mn) appears as interveinal chlorosis with a herringbone pattern affecting only basal leaves; terminal leaves are not affected. It is usually associated with high-pH soil. Reducing soil pH and foliar treatments with chelated manganese correct this problem for several seasons.

Weed Control

Weeds can have a dramatic effect on tree growth by competing for soil moisture, physical space, and nutrients, and some weeds may have an antagonistic or allelopathic effect on trees. Experiments comparing various weed control methods have demonstrated that the growth of young trees can be reduced by one-third to one-half in the first few years if weeds are allowed to compete with trees.

One of the best ways to maintain a weed-free area under home orchard trees is with an organic mulch. The mulch keeps the soil moist and reduces evaporation, and as it breaks down, it releases nutrients to the tree. Mulch must be at least 3 inches deep to adequately control weeds and must be reapplied periodically to maintain that depth. Other alternatives to organic mulches, such as heavy-duty weed cloth, eliminate the need for frequent reapplication. The best weed cloth blocks all the light, controls weed growth, allows water to pass through, and lasts 5 to 10 years. Another advantage is that it can be easily cleaned of fallen leaves and fruit to prevent the spread of diseases. Mechanical cultivation with a tiller or hand hoe also suppresses most weeds; the important thing is to keep the area free of weeds from the beginning of growth in the spring until leaf fall.

In the dormant period, it is not critical to maintain a weed-free area under the trees: cover crops or ornamentals can be grown to improve the soil or for the sake of appearance. Mature trees can tolerate more weeds, turf, or cover crops growing within their drip line since they already have an established root system, are full sized, and don't need to grow as much. Do not allow lawns to grow within 2 feet of the tree trunk. This prevents crown rot and trunk damage from mowing or edging tools, especially weed trimmers, which often girdle the trunk.

Harvesting and Storage

Optimal harvesting dates

Determining the optimal harvesting date for fruit and nut crops is as much an art as a science. Expect the harvesting date to vary a little from year to year because maturation and ripening in temperate fruits and nuts depend on many factors

including tree vigor, age, water stress, heat unit accumulation, heat stress, weather, cultural practices, and other factors.

Fruits

Horticulturists distinguish between maturity and ripeness. Ripe fruits are ready to eat; mature fruits have developed to the stage in which they can ripen after harvest. Maturation involves a number of physical, physiological, and biochemical changes, such as a decrease in skin chlorophyll; an increase in carotenes, anthocyanins, and xanthophyll pigments; a decrease in organic acid content; an increase in sugars, soluble solids, and soluble pectins; and changes in respiratory activity.

The best criterion for determining fruit maturity and ripeness is taste. In addition, several other criteria can be used to evaluate the maturity of the fruit crop and help decide when to harvest: number of days from full bloom, flesh firmness (pressure test), skin color, flesh color, seed color, and starch or sugar content testing. The starch test and sugar tests (soluble solids, or brix) are used commercially on apples to determine whether the fruit meet minimum harvest standards. One primary reason for growing fruit trees at home is to let fruits ripen fully, beyond the minimum of maturity and ripeness.

Whether fruits should be harvested when fully ripe or physiologically mature often depends on the intended usage—fresh eating, canning, freezing, or drying. In the home orchard, fruits intended to be eaten right away are harvested when they are fully ripe. Pears, winter apples, fresh plums, apricots, and peaches can also be harvested when they are "firm mature" (physiologically mature) but unripe, then allowed to ripen off the tree for fresh eating later. Prunes used for drying should be harvested more mature than those used for canning. European pears are usually harvested when they are green and firm, stored at least 1 week at 32°F, then transferred to room temperature and 85% relative humidity to ripen.

Nuts

Nuts should be harvested when they are ripe. Hazelnut (filbert) maturity occurs when filberts are shed from the husk in September, October, or November. When they drop, they are fully mature, but they must be cured and dried to 8 to 10% moisture content. (Since it is difficult to test nuts for moisture content, taste them and compare them to commercially dried nuts.) Walnuts are mature 1 to 4 weeks before hull cracking (dehiscence). They can be dried to 5% moisture (on a kernel basis) immediately after harvest. Almonds are mature and ready for harvest when they are loose enough to be knocked from the tree and hulled. Mature pecans do not fall from the tree all at once; they reach maturity when the husks open from around the nuts. Pistachios reach maturity when their skin changes from translucent to opaque and the hull shrivels and separates easily from the shell. Chestnuts mature over a period of weeks from September into November, depending on the climate. When mature, they fall easily from the tree and separate easily from the burr. Unlike other nuts, they should be stored at 32°F and high relative humidity before being eaten fresh. They can also be peeled and dried for later rehydration or grinding into chestnut flour.

Harvesting Technique

Harvest most fruits by twisting and lifting the fruit up, not by pulling straight down from the spur or branch. Be careful to minimize bruising and injury. Place fruits gently in your harvesting container; do not just drop them in. Softer fruits require careful handling to avoid bruises, and firmer fruits require careful handling to avoid skin punctures. Prevention of bruises and skin damage greatly increases the storage life of fruits.

Pests, Diseases, and Environmental Stresses

A number of pests, diseases, and environmental stresses attack temperate tree fruit and nut crops in California. Certain crops and cultivars are more susceptible to pests and diseases, but healthy trees that are irrigated and fertilized properly and that receive the kinds of preventive care described in table 16.5 should have little pest damage. If the home gardener is willing to overlook an occasional chewed leaf or fruit blemish and instead focus on the more serious enemies that compromise the overall health of the trees, the pest control program will be efficient and rewarding.

Common Pests

Table 16.6 describes some of the more common insect and mite pests, diseases, and environmental stresses that attack tree fruit and nut crops, what the symptoms look like, the probable causal agent, which parts of the plant are attacked, and what can be done to control the problem. Two important University of California publications on this subject are *Pests of the Garden and Small Farm* (Flint 1998), which has many pages of easy-to-use information and excellent color photographs of pests, diseases, and environmental stresses, and *Diseases of Temperate Zone Tree Fruit and Nut Crops* (Ogawa and English 1991), a more technical publication that presents a thorough coverage of the biotic and abiotic diseases of these crops. Table 16.6 was adapted from these two UC publications and from other UC references listed in the bibliography at the end of the chapter. The UC IPM website, ipm.ucdavis.edu, contains up-to-date, comprehensive information. Consult the bibliography for further information on pest problems in temperate tree fruits and nuts. The UC IPM Pest Notes, ipm.ucdavis.edu/PMG/menu.homegarden, are also an excellent source of information about specific insect and disease problems.

Since this chapter discusses numerous crops attacked by many of the same pests and diseases, table 16.6 is organized so that each pest or disease is presented once with useful information about the temperate tree fruit and nut crops attacked. Thus, unlike other tables in this chapter that are structured with separate categories for the pome fruits, stone fruits, nuts, vines, and miscellaneous temperate fruits, this table is organized by the type of pest (fungi, bacteria, and nematodes) because many pests and diseases have wide host ranges. Some pests and diseases attack practically all deciduous tree fruit and nut crops, whereas, others, as noted in the table, have a limited host range or can be much more damaging to the pome fruits than the stone fruits, for example. Sometimes, the name of the disease changes depending on the crop or plant part attacked. The "Comments" section of table 16.6 notes which crops are hosts for each pest or disease described.

For comprehensive information about postharvest diseases or other disease information organized by specific crop or crop group (pome fruits, stone fruits, nut crops, vines), refer to *Diseases of Temperate Zone Tree Fruit and Nut Crops* (Ogawa and English 1991); see also the UC IPM Pest Notes, ipm.ucdavis.edu/homegarden. Postharvest and storage diseases (Alternaria rots, Botrytis and other molds, Aspergillus, mycotoxins, etc.) are not covered in table 16.6, which focuses on the preharvest enemies of your home fruit and nut trees.

Temperate tree fruit and nut crops are susceptible to attack from many fungal, viral, and bacterial pathogens. However, pest and disease problems should be few if trees are healthy when purchased and have tolerant rootstocks (see the section "Cultivars" in this chapter), and if preventive measures are taken to reduce or eliminate conditions favoring these organisms. The damage potential of many temperate tree fruit and nut crop diseases and pests depends on the rootstock and scion combination, soil conditions, site

Table 16.6.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Caterpillars		
Small hole in the fruit skin with brown granular material that looks like sawdust coming out. At the core, fruit turns brown and has a worm in it. Fruit may drop off prematurely.	codling moth *(Cydia pomonella)*	White to pink caterpillars with a mottled brown head; not too distinctive. The most serious caterpillar pest of apples and pears. Larvae penetrate fruit and bore into the core or cause more shallow blemishes on the fruit surface. One of the few caterpillars found inside apples and pears. Eggs, which are difficult to find in the field, are laid on fruit or nearby leaves. Codling moth is very difficult to control organically in the home garden. Practice good sanitation. Clean up fallen fruit in spring daily and spray the trees with summer oil or conventional insecticide timed when symptoms first appear. Spray two or three times in the growing season. See *Pests of the Garden and Small Farm* and Pest Note *Codling Moth* (Caprile 2011), and UC IPM publications on apples and pears listed in the bibliography. Codling moth is a less serious pest on plums and other stone fruit than on apples and pears. The caterpillars often bore into stone fruits all the way to the pit.
Green walnuts drop off or dry up on tree. Little webbing in nut. Older nuts are worm infested. Hull with masses of brown fecal material protruding from entry holes. Most caterpillars leave nuts before harvest.	codling moth *(Cydia pomonella)*	White to pink caterpillars with a mottled brown head; not too distinctive. The most serious caterpillar pest of walnuts. Larvae feed on nut kernels. Early-season cultivars are most susceptible, with damaged nuts dropping off trees. Later in the season, damaged nuts remain on trees but kernels are inedible. One of few caterpillars found inside walnuts. Eggs are laid on nuts or nearby leaves. Practice good sanitation. Clean up fallen nuts in spring daily for maximum effectiveness. See *Pests of the Garden and Small Farm* and *Integrated Pest Management for Walnuts* (Strand 2003) for additional control methods.
Leaves eaten in spring. Small gouges in newly set or young fruit. Damaged areas later scab over. Rarely attacks older fruit.	western tussock moth *(Orgyia vetusta)*	Long hairs make the caterpillar easy to identify. Young larvae are black with long bristles. Older larvae have numerous red and yellow spots, four white tufts of hair, and many more groups of bristles. Look for light brown pupal cases in the dormant season.This caterpillar attacks apples, cherries, plums, prunes, and walnuts. It can defoliate deciduous fruit and nut trees in spring or take bites out of young fruit. Check for eggs in winter and larvae in spring. Most damage occurs in mid-Mar and mid-May. Removing egg masses and newly hatched caterpillars should provide sufficient control in backyard trees. Oil spray in winter kills egg masses on deciduous trees. Bt is an effective control on most crops.
New leaves have holes and are webbed and rolled together. Caterpillars also feed on buds and developing fruit, often rolling and webbing fruit and leaves together. Deeply gouged young fruit may fall to the ground. Less severely damaged fruit reach maturity badly misshapen or with deep bronze-colored scars and rough surfaces. All leafrollers wriggle and drop on a spun thread when disturbed.	fruittree leafroller *(Archips argyrospilus)* omnivorous leafroller *(Platynota stultana)* green fruitworms (various spp.) orange tortrix *(Argyrotaenia citrana)*	Attack apples, pears, almonds, and other stone fruits. Fruittree leafroller caterpillars are green with a shiny black head and feed on young leaves, buds, and developing fruit, webbing leaves and fruit together. Damage to fruit may expose it to decay organisms. Most damage occurs in spring and early summer. One generation per year. Handpick damaged tissue and destroy. Omnivorous leafroller attacks kiwi and most fruit trees. Has many generations per year. Caterpillars are so translucent their main blood vessel is visible down their backs. General sanitation and natural parasites are effective controls. Green fruitworms include at least 10 species of caterpillars. They attack apples, pears, apricots, cherries, plums, and prunes. One generation per year. Damage occurs in spring on very young fruit. Bt is a control, but be certain the crop is specifically listed on the Bt product used. Orange tortrix attacks stone fruits, kiwifruit, and apples mostly in coastal areas and interior valleys of coastal areas. It is greenish orange color, feeds in web; when disturbed, it hisses and drops on a silken thread. Prefers a tree's top half to the bottom half. Control can be achieved by handpicking on small trees or by applying a Bt product labeled for use on the crop in an early-spring spray. Thinning apples to one or two fruit per cluster reduces damage. *Pests of the Garden and Small Farm* has excellent photographs of leafroller pests and more detailed information.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Caterpillars enter nuts after hulls or husks split, feed directly on nut meats, and contaminate nuts with large quantities of excrement and webbing, which are the telltale signs that identify this pest as the causal agent.	navel orangeworm (*Amyelois transitella*)	Milky white to pink worm with reddish brown head. Pair of crescent-shaped marks on second segment behind head distinguishes it from codling moth, oriental fruit moth, and other larvae found in nuts. Attacks almonds, pistachios, and walnuts. In spring, eggs are laid singly on damaged or mummy nuts that remained on trees after harvest and through the winter. Later generations lay eggs on hulls of newly forming or ripening nuts. In winter, check trees for unharvested mummy nuts. Remove and destroy them by Feb 1. Crack open mummy nuts to gauge the extent of infestation. Insecticide sprays should be unnecessary if sanitation is practiced and nuts are harvested as soon as hull split occurs in almonds and as early as possible in walnuts. Store nuts in sealed containers as soon as they are dry. Parasitic wasps and nematodes that attack navel orangeworms have been used to control this pest.
Caterpillars bore into the growing shoots of twigs and ripening fruit or nuts. Shoots and leaves wilt and die back 1 to several inches from the growing tips of twigs in spring. Small worm with dark brown bands may be found inside each affected shoot. Ripening fleshy fruit (peaches, nectarines) infested with worms near stem end, apricot fruit near seams. Almond kernels have superficial scarring, no webbing. More superficial feeding on green and ripening fruit than oriental fruit moth.	peach twig borer (*Anarsia lineatella*)	Black head, chocolate-colored body with white segments in between, giving a banded appearance. Maximum length is about $^{1}/_{2}$ in. Attacks almond, apricot, nectarine, peach, plum, and prune. Monitor by looking for overwintering "cells" in the fall, winter, and early spring. The cells look like minute, chimney-like reddish piles of excrement and sawdust on the bark surface of 1- to 4-year-old wood. During the growing season, check trees for wilting or wormy shoot tips and wormy fruit. Pheromone traps may be used to monitor adult males. Natural enemies, although there are many, do not provide reliable control. The most reliable control is a dormant oil and organophosphate insecticide spray applied in winter to kill overwintering caterpillars on tree branches. Good coverage will reduce populations more than 95%. Dormant oil alone will not kill peach twig borer. Once fruit and twigs are infested in the spring, control is much more difficult. Sprays during the growing season must be applied to control hatching larvae before they enter twigs or fruit.
Damage to twigs similar to peach twig borer, but caterpillars bore right into the center to feed around the pit unlike peach twig borer, which feeds superficially. No webbing, which distinguishes it from the navel orangeworm in almonds.	oriental fruit moth (*Grapholita molesta*)	White or pink with brown head; $^{5}/_{8}$ in long. Attacks almond, apricot, nectarine, peach, plum, and prune. Tiny disk-shaped eggs are laid on leaves, twigs, and fruit. Look for caterpillars in wilted shoots and fruit. Prefers to feed in tops of trees. Sample fruit in treetops to monitor for presence. Dormant oil sprays do not control this pest nor do naturally occurring biological controls.
Aphids and associated sooty mold fungi		
Black film on leaf surfaces.	sooty mold fungus	Most active in cool, moist conditions. This fungus feeds on honeydew excreted by aphids, mealybugs, scale insects, and whiteflies. Sooty mold should be washed off leaves because it can reduce photosynthesis and tree productivity if prolonged. Wash off fruit. Cosmetically unappealing, but usually no serious harm. Apply control measures for the causal pest and sooty mold will disappear.
Distorted, curled leaves, stunting of shoots, sticky honeydew exudates on leaves, which leads to growth of sooty mold fungus. Ants are often associated with aphids on tree crops. If you see ants climbing the tree trunks, check for aphids on the limbs and leaves above.	aphids	Small, soft-bodied insects. Dozens of species in California. Green, yellow, brown, red, or black, depending on species and food source. Pair of protruding cornicles (exhaust pipes) at back end of body. Aphids attack many fruit and nut trees in California. Usually feed in dense groups on stems or leaves. Many generations per year. Can produce asexually without mating or laying eggs. Many species can develop from newborn nymph to reproducing adult in less than 2 weeks. Each adult can produce up to 100 offspring per week, so populations can increase rapidly if not controlled. Small numbers of aphids do not cause much damage and can be tolerated. Check garden and orchard for aphids twice weekly when plants are growing rapidly. Curled, distorted leaves protect aphids from natural enemies or pesticides. Check undersides of leaves, where aphids prefer. Control needed only for heavy infestation on young trees. Dislodge with jet streams of water or use insecticidal soap or oil sprays. Oil treatments on dormant trees kill overwintering aphid eggs if applied as eggs begin to hatch in early spring. Oil treatments are effective against woolly apple aphid, green apple aphid, rosy apple aphid, mealy plum aphid, and black cherry aphid. Insects suck sap from tender, new growth. Honeydew provides a medium for growth of sooty mold fungus.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
White, cottony masses on woody parts of trees, often near pruning wounds. Warty growths on limbs and roots. Clear, sticky honeydew and black sooty mold on foliage and fruit. Tree declines if root infestation heavy for many years.	woolly apple aphid	Reddish insect < 1/8 in long covered with white, cottony material. Very sluggish movements. Aphids spend winter on roots and branches of apple tree. Little visible cottony material. In summer and fall, successive generations migrate from roots to branches and vice versa. Bands of sticky substances around trunks and branches can help prevent migration. Dormant oil sprays kill colonies on branches. Not easily washed off with soapy water solution. No chemical control for root colonies. Tiny parasitic wasps are important natural control agents. Aphids can become numerous when these wasps are killed by insecticides.
New leaves severely distorted and curled; shoots get twisted. Large amounts of clear, sticky honeydew drip onto foliage and fruit. Many young apples become puckered and fail to grow. Clusters of small, sedentary purplish insects in curled leaves and on fruit stems.	rosy apple aphid	Pear-shaped insect < 1/8 in long with two tiny "pipes" protruding from back end. Young are dark green. Mature are reddish to purplish and covered with powdery bloom. Winged are brownish green. Spring pest only. Overwinters as egg on bark of apple tree. Young appear with first new leaves. Migrates to plantain and ribgrass in Jun. New growth will cover up damage by summer. Dormant oil kills overwintering eggs. See *Pests of the Garden and Small Farm* for other control measures and the UC IPM Pest Note *Aphids* (Flint 2013).
New growth stunted; large amounts of clear sticky honeydew and black sooty mold on foliage and fruit. Colonies of small, sedentary yellowish green insects on new shoots.	green apple aphid	Pear-shaped insect < 1/8 in long with two tiny "pipes" protruding from back end. Young are dark green. Mature are bright yellowish green. Winged are yellowish brown. On apple all year. Most serious where climate remains cool and moist. Overwinters as egg on bark of tree. Young aphids appear at bud burst. Dormant oil sprays kill overwintering eggs. However, infestations can still be severe due to movements of winged aphids from other trees. Shoot damage is primarily a concern on young trees. See *Pests of the Garden and Small Farm* (Flint 1998) for other control measures.
In spring, foliage infested with pale green, slow-moving insects that produce white, mealy substance. Leaves, fruit covered with clear sticky honeydew that turns black because of sooty mold fungus growth. Fruit may split.	mealy plum aphid	Pear-shaped insect < 1/8 in long with two tiny "pipes" protruding from back end. Pale green. Attacks apricots, plums, and prunes. Overwinters as egg on tree. Leaves tree for weeds in Jul; returns in early winter to lay eggs. Dormant oil spray kills overwintering eggs. Often, only one or two limbs affected. Control measures seldom necessary. New growth will cover up damage by summer. Japanese hybrid plums unaffected.
In spring, leaves severely curled by clusters of small, sedentary, shiny black insects.	black cherry aphid	Pear-shaped insect < 1/8 in long with two tiny "pipes" protruding from back end. Black, shiny. Some winged, others wingless. Attacks cherries. Overwinters as egg on bark of cherry tree. Leaves tree for weeds in midsummer; returns in autumn to lay eggs. Dormant oil spray reduces spring population. Spring pest only. New growth will cover up damage by summer. See *Pests of the Garden and Small Farm* for other control measures.
Leaves become curled, covered with tiny, sedentary greenish insects.	green peach aphid	Green, pear-shaped aphid. Attacks peaches and nectarines. Chemical control usually not necessary.
Leaves distorted, new foliage stunted. Maturing fruit looks russeted. Clusters of sedentary, greenish insects on new shoots.	various aphids	Attacks pears. Minor problem in home orchards. Distorted leaves soon covered up by normal foliage.
Leaves, nuts covered with clear, sticky honeydew. Turns black due to sooty mold growth. Leaf drop may occur. Nuts become sunburned. Size, quality of nuts reduced. Tiny, yellow insects along veins on leaf undersides.	walnut aphid	Tiny insect, 1/16 in long, oval to pear shaped. May have two dark bands across back in fall. Moves sluggishly. Attacks walnuts. Many generations per year. Overwinters as egg in rough places on twigs. Not much of a problem because an introduced parasitic wasp usually controls this pest. See *Pests of the Garden and Small Farm*.
Boring insects that damage trunks and major limbs		
Larvae bore in the crown area of many fruit tree species. Small piles of reddish brown frass visible at base of tree trunk. Tree looks weak.	peachtree borer *(Synanthedon exitiosa)*	Larva is light brown or pink with darker head. Attacks almond, apricot, nectarine, peach, plum, prune (stone fruits). Occurs primarily in the Santa Clara Valley and Contra Costa County. Eggs are laid on bark at the base of tree trunks in summer. Hatching larvae tunnel into the tree at or below ground level. Larvae feed in the crown area and burrow into tree, leave reddish brown frass at base of tree trunk. Pupate in spring near their burrows or in soil. Adult moths emerge about a month later. One generation per year. Monitor your trees in the fall for frass and sap exuding from tunnels. Use good sanitation methods. Home gardeners can use the instructions in *Pests of the Garden and Small Farm* and kill larvae with a small knife. Major problems are on newly planted trees or trees weakened by attack from other pests, poor cultural practices, or sunburn.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Larvae bore into aboveground areas on trunk previously injured by sunburn. Bark may die or girdle. No frass. Young larvae feed under bark in rapidly growing wood. May kill young tree.	Pacific flathead borer *(Chrysobothris malis)*	Light-colored larvae with distinctive flattened enlargement just behind the head. Attacks almond, apricot, nectarine, peach, plum, prune (stone fruits), apples, other pome fruits, and walnuts. Occurs throughout the state. Attacks aboveground portions of trunk previously damaged by sunburn or other causes. Larvae excavate tunnels below the bark; sap will seep out. No frass. Pupate in spring within trunk. Wrapping or painting the trunks of newly planted trees from 1 in below the soil line to 24 in above the ground with white indoor latex paint or whitewash protects the trunk from sunburn and borer invasion. Spraying for this insect is not recommended.
Sap leaking from many small holes on trunks or scaffolds. Tiny black beetles visible under bark. May girdle or kill young tree.	shothole borer *(Scolytus rugulosus)*	Tiny black beetles, $1/10$ in long. Attacks almond, other stone fruits, apples, and pears. A pest of trees already weakened by root diseases, insufficient irrigation, sunburned limbs, other borers. Females bore small holes, which look like shot holes, in the bark and lay eggs in a gallery 1 to 2 in long running lengthwise down the cambium layer of the tree. Hatching larvae feed and excavate secondary galleries at right angles to the egg gallery. Two or three generations per year. Larvae spend the winter in their galleries beneath the bark. Prevent by keeping trees healthy with sufficient irrigation and fertilizer and use good sanitation and cultural practices. The presence of shothole borers usually indicates that there was serious plant stress. Prune out infested area and burn the wood before growing season starts. Spraying for this insect pest is not recommended.
Scale insects		
Armored scales: Water stress, yellow leaves. Twigs, limbs may die. Bark cracks, gums. Blemishes, halos on fruit. Trees may die. *Soft scales*: Reduced tree vigor but tree not commonly killed. Honeydew, sooty black mold, and ants. Ants are good indicator of soft scale infestation. Most soft scales infest leaves and twigs but do not attack fruit directly.	scale insects	Attack all types of fruit and nut trees and kiwifruit. Unusual-looking pest; many people do not recognize scales as insects. Adult females and many immature forms do not move and are hidden under a disklike waxy covering. Adult males have wings. Scales have long piercing mouthparts used to suck juices out of plants. May occur on twigs, leaves, branches, or fruit. Severe infestations can cause overall decline and death of trees. Most scales have many natural enemies that control them. Others are well controlled with oil sprays in the dormant season. Two groups of scales, armored scales and soft scales, are important fruit tree pests. Armored scales have a hard cover that is separate from their body and lose their legs a day or two after hatching from eggs. Soft scales have smooth or cottony covers attached to their bodies. Some soft scales retain their legs for life and can move around. Like aphids, soft scales excrete copious amounts of honeydew, attracting ants and causing growth of sooty mold fungus. Armored scales have many generations per year; soft scales, one generation per year. See UC IPM Pest Note *Scales* (Dreistadt 2007).
See general comments above for armored scales. Twigs and branches heavily infested with this scale retain their leaves during winter and are easy to spot.	San Jose scale *(Quadraspidiotus perniciosus)*	Armored scale. Adult females are round, $1/10$ in in diameter, with gray-brown to black cover. If cover is removed scale beneath is bright yellow. Attacks most deciduous fruit and nut trees. Specially refined horticultural oils called supreme or superior-type oils are effective against San Jose scale. When applied as a delayed dormant spray just before bud swell, oil treatment can also kill some of the overwintering mites, aphids, or caterpillar eggs on woody portions of tree. Make treatments before bud swell and when trees are not water stressed. Apply right *after* a rain or foggy weather. Monitor by examining trees, especially during dormant season. Check prunings for scale infestation. Natural enemies provide some control; oils do not harm natural enemies. San Jose scale is encouraged by spraying conventional insecticides for control of other pests, which kills the natural enemies that usually control the scale.
See general comments above for armored scales and for San Jose scale.	walnut scale *(Quadraspidiotus juglansregiae)*	Armored scale. Adult females are yellow underneath cover. More indented than San Jose scale. Attacks walnuts. See comments for San Jose scale.
Not found on leaves or fruit. Feeds on bark, sometimes causing leaves to yellow and dry up. Usually only a few limbs affected at first.	oystershell scale *(Lepidosaphes ulmi)*	Armored scale. Resembles a mussel shell in shape. Attacks most deciduous fruit and nut trees, especially apples, pears, and walnuts. Survey trees regularly, examining bark below yellowing or dried-up leaves. Prune out infested limbs. Oil sprays are effective in late May or early Jun, when crawlers are present. Oils applied during the dormant season are not effective because susceptible stages are not present at that time.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Round, red-brown scales on fruit, leaves, and twigs. Leaves may yellow and drop, and twig dieback may occur. Damage most visible in late summer and early fall. Reduced tree vigor.	California red scale *(Aonidiella aurantii)*	Armored scale. Adult males are tiny yellow-winged insects almost identical to adult male San Jose scales. Can be distinguished from yellow scale *(Aonidiella citrina)* under a microscope. Attacks olives. Natural enemies (parasitic wasps of *Aphytis* and *Encarsia* spp.) can provide good control in many parts of California. If needed, oil spray should be applied between Jul and Sep. See general comments for armored scales.
Fruit and leaves covered with honeydew, sooty mold, ants. Tree vigor reduced. Scales on leaves, twigs, rarely on fruit.	citricola scale *(Coccus pseudomagnoliarum)*	Soft scale. Resembles brown soft scales except that immatures are mottled dark brown and matures are gray. Attacks walnut, pomegranate. One generation per year. Look for adults in spring and early summer on twigs. In summer and fall check undersides of leaves for immature scales. Natural enemies and oil sprays are effective controls. Keep ants out of trees because they protect scales from natural enemies. Citricola is more serious in the San Joaquin Valley than in southern California. *Metaphycus* spp. parasitic wasps provide some control in southern California. Late summer or fall is best time to control.
See general comments for soft scales.	European fruit lecanium *(Parthenolecanium corni)* calico scale *(Eulecanium caerasorum)*	European fruit lecanium is also known as brown apricot scale. Domed shell is shiny brown, about 3/8 in in diameter with several ridges on the back. Attacks most deciduous fruit and nut trees. Calico scale adult has mottled white/brown calico pattern. *Metaphycus* spp. parasites are effective control for both types. Dormant oils must be applied by mid-Jan.
See general comments for soft scales.	frosted scale *(Parthenolecanium pruinosum)*	Attacks walnuts and pistachios. Frosted scale has a frosted, waxy coating in spring from early Mar to mid-Apr. Later, wax erodes and scale looks shiny dark brown. See comments for calico scale for control measures.
Mealybugs		
Fruit and leaves covered with honeydew and sooty mold. Mealybugs feeding in dense colonies. Fruit drop can occur if mealybugs feed along a stem. (*Pears*: whitish, cottony masses in calyx end of fruit, at base of twigs, and fruit clusters.)	mealybugs (*Pseudococcus*, *Planococcus* spp.)	Soft, oval, distinctly segmented insects covered with mealy white wax. Adults about 1/8 to 1/4 in long. Sluggish movements. Attacks apples, pears, and apricots. Overwinters in loose bark as nymphs or eggs. Adults have waxy protective coat. Natural enemies usually control. Eliminate ants because they feed on honeydew produced by mealybugs and protect them from natural enemies. Mealybug populations can decrease in summer due to their heat sensitivity. Control by handpicking them, hosing them off with water, or applying insecticidal soap or oil sprays. Mealybugs extract plant sap from stems, leaves, and shoots, reducing tree vigor.
Ants		
Ants feeding on twigs, bark, leaves, and honeydew excreted by other insect pests. Argentine worker ants travel in distinct trails.	Argentine ant *(Iridomyrmex humilis)* Southern fire ant *(Solenopsis xyloni)*	Ants feed on honeydew excreted by soft scales, mealybugs, and aphids. Ants can interrupt biological control of these pests. Control ants by denying access to the canopy. Apply a band of sticky material to base of trunk that mechanically impedes ants. Prune the canopy up (above 30 in) off the ground so that ants can't get into the tree without climbing the trunk.
Snails		
Holes in leaves and fruit; slimy trails.	brown garden snail *(Helix aspersa)* gray garden slug *(Agriolimax reticulatus)*	Brown garden snail is about 1 in diameter; brown snail with distinct color pattern; gray garden slug is a snail relative that lacks a shell. Most active at night and early morning when it's damp. Manage by skirt pruning and trunk treatment. Release predatory decollate snails *(Rumina decollata)* in counties where it is legal. Use wooden boards with cleats for monitoring. Remove collected snails and slugs daily. Crush to destroy or use a 50:50 solution of household ammonia and water in a spray bottle. Keep ammonia solution off leaf surfaces since it can damage plants. Copper barriers, such as trunk banding, can be effective.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Mite pests		
Leaves have pale yellow stippling on upper leaf surfaces. No webbing. Bright red globular eggs laid on bark or leaves. Adults found mostly on young leaves.	red mites (*Panonychus* spp.)	Barely visible (use hand lens). Long bristles protrude from adult's back. Attacks almost all fruit and nut trees. Overwinters in egg stage on bark of deciduous trees. New generation every 2 weeks in spring. Natural enemies often are sufficient control in unsprayed home orchards. If not, a supreme or superior-type delayed dormant oil spray just as eggs are about to hatch should keep mites below damaging levels.
Leaves, twigs, fruit covered with webbing; stippling on leaves. Mites visible with hand lens on bark or leaves.	webspinning spider mites (*Tetranychus* spp.)	Barely visible (use 10x hand lens); looks like tiny moving dots to naked eye; < 1/20 in long. Arachnid, not an insect. Attacks almost all fruit and nut trees. Spider mites live in colonies on lower leaf surfaces. Webbing distinguishes them from mite species. Overwinter on deciduous trees as red or orange females under rough bark scales, in ground litter, and trash. Eggs laid in spring. Numbers increase in Jun-Sep. One generation per week in hot weather. Mites cause damage by sucking cell contents from leaves. Damage compounded by water stress. Provide adequate irrigation. Dusty conditions favor spider mites. Many natural enemies limit their numbers, but spraying for insect pests can lead to outbreak of mites because mite enemies are killed by the insecticide, and because some insecticides can increase nitrogen levels in leaves, favoring mite reproduction. Forceful sprays of water and insecticidal soaps help to control. See UC IPM Pest Note *Spider Mites* (Godfrey 2011).
Stippling of whitish gray spots on young leaves. No webbing. Leaves do not drop.	brown mite *(Bryobia rubrioculus)*	Larger than most other mites; produces no webbing; causes leaf stippling. Attacks stone fruits, almonds, apples, and pears. Largest of common pest mites in California but rarely causes enough damage to warrant treatment in backyard orchards. Many natural enemies. Found on leaves, twigs, wood.
Rust mites and silver mites feeding on leaf or fruit surfaces. Blister mites feeding in protected areas in buds or blisters. Damage is noticed long before these microscopic mites are detected. *Rust mites*: Fruit becomes rough, brown, and russeted, especially at stem and flower ends. Foliage looks dry, rusty. *Blister mites*: Leaves and flower buds develop reddish blisters that later turn brown or black. Fruit develop sunken, brown, russeted areas and may become deformed.	Eriophyid mites: peach silver mite *(Aculus cornutus)* pearleaf blister mite *(Phytoptus pyri)* pear rust mite *(Epitrimerus pyri)*	Attacks peach, pear, pomegranate, and apple, among others. Includes the blister, rust, bud, and gall mites. These mites have only four legs instead of the typical eight legs of arachnids. Their legs appear to be coming out of their heads. These mites are much smaller than the spider mites and red mites; you need a 15x to 20x hand lens to see them. They have many generations per year. Overwinter as nonfeeding adults behind leaf bud scales or any other protected 1- to 2-year-old wood. Rust mites feed until no more new foliage develops. Control measures seldom necessary for them. Damage is mostly cosmetic, affecting fruit appearance. For rust mites and blister mites on crops other than pomegranate, an oil spray with lime sulfur in Oct or Nov decreases population for the following season and prevents blister mites from moving deeper into buds. Sulfur dust is an effective control on all these crops as long as summer temperatures are below 85° to 90°F.
Miscellaneous insects		
Leaves have brownish patches from top layer being eaten. Later, leaf tissue eaten completely through, leaving fine network of veins.	pearslug *(Caliroa cerasi)*	Olive green to blackish slimy insect up to 1/2 in long with head end widest part of body. The adult is a sawfly. Attacks cherries, pears, plums, prunes. Two generations per year. Adults emerge in early spring and lay eggs in leaf tissue. Mature larvae enter soil to pupate. Second generation that appears in summer does the most damage. Pick pearslugs off by hand and dislodge from foliage with strong stream of water. Insecticidal soap may be effective. Road dust applied to foliage can kill them but should be washed off after several days to discourage spider mites.
Fruit and foliage sticky, becoming black with sooty mold. Stunted vegetative growth or tree defoliated. Beads of clear, sticky honeydew enclose tiny, yellowish insects on leaves.	pear psylla	Tiny insect up to 1/10 in long. Yellow in immature stages, reddish brown as adult. Dark spot on back. Clear wings held rooflike over body. Attacks pears. About five generations per year. Adult overwinters in sheltered places in bark or underground. Eggs laid on or near new foliage. Dormant oil spray kills many overwintering adults. Eggs and mature young (nymphs) are resistant to insecticides, but adults and smaller nymphs can be controlled during growing season with two or three oil sprays applied weekly. Pear decline disease is transmitted by this insect.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Small black spots on husk become large, blackened areas that remain soft, unsunken, and smooth. Areas damaged by walnut blight dry up. Hull difficult to remove from shell. Shell darkly stained. Nut meat not affected. Infested nuts tend to remain on tree.	walnut husk fly	White to yellowish maggots up to 3/8 in long. Adult fly is small, brown, has yellow spot on back, three dark bands on each wing. Attacks walnuts. Maggots are found in blackened areas of hull, never inside shell. One generation per year. Eggs laid in hull from late Jul to early Aug. Larvae pupate in ground. Adult flies emerge following summer. Most home orchardists ignore this pest because nut meats are unaffected. For control measures, see *Pests of the Garden and Small Farm*.
Pin-pricked holes on rotten fruit with tunnels that distort fruit shape and color. Fruit turns brown and rots as it ripens.	olive fruit fly	White to yellowish maggots up to 3/8 in long. Adult fly is small, brown, and has a black spot on the tip of each wing. Attacks olives. Maggots and pupae are found inside the fruit, leaving tunnels and blackened areas that cause the fruit to rot as it ripens. Several generations per year, which can cause up to 90% damage. Control by spraying GF-120 bait on a weekly basis from pea-size stage to harvest, or by spraying a barrier film (kaolin clay) onto fruit from pea-size stage to harvest, or by putting up an attract and kill trap. Liquid bottle traps can reduce damage. Trapping can reduce damage.
Nematodes		
Fruits decreased in size, yellowed leaves, twig dieback, general loss of vigor. General stress symptoms; premature autumn leaf loss.	root knot nematode (*Meloidogyne* spp.) root lesion nematode (*Pratylenchus* spp.) citrus nematode (*Tylenchulus semipenetrans*)	Nematodes, microscopic wormlike pests, are tiny eel-like soil-dwelling roundworms that feed on roots. By feeding on roots, nematodes cause general tree decline. Root knot nematodes cause distinct swellings (galls) on roots of infested trees. Root lesion nematodes reduce growth of young feeder roots and produce lesions on root surfaces of many, but not all, damaged trees. One of the simplest management strategies is to plant scions on nematode-resistant or nematode-tolerant rootstocks (Nemaguard or Nemared). See *Pests of the Garden and Small Farm* for other control methods.
Diseases caused by fungi		
Most deciduous fruit and nut trees worldwide are affected by diseases known as crown rot, root rot, collar rot, and trunk rot caused by *Phytophthora* spp. fungi. In California, root and crown rots caused by *Phytophthora* spp., discussed below, kill more almond, apple, cherry, nectarine, and peach trees than perhaps any other disease. All species of stone fruit, pome fruit, kiwifruit, chestnut, and walnut are more or less affected.		
Leaves turn yellow, red, or purple, and drop. Tree looks drought stressed. Beads of sap ooze from trunk lesions. Gumming may be visible in spring. Inner bark is brown, slimy, and/or gummy, but the discoloration does not extend into the wood. Bark can dry, harden, and crack. Decline of tree due to disruption of water and nutrient transport may be rapid.	Phytophthora crown rot (*Phytophthora cactorum* and at least 15 other *Phytophthora* spp. that infect the tree trunk and crown)	Attacks all deciduous fruit and nut trees. Prevent this disease with good water management. Keep trunk dry. Do not allow sprinkler water to hit the trunk. Scrape away all diseased bark and include a buffer strip (about 1 in) of healthy light brown to greenish bark around margins. Allow to dry. Repeat if infection recurs. Keep mounded soil and water away from trunk. Improve ventilation by removing branches that touch the ground. Avoid injuring bark with lawnmowers, weed whackers (the worst), and pruning tools, since wounds give fungus an easy entry to cause disease.
Trunk cankers at the base of older trees, originating at or below ground level. Canker appears as a dark region with a red, resinous exudate that dries to a white, crystalline deposit. Underneath the superficial canker is an orange-tan to brown lesion, instead of the normal white or cream-colored tissue. Lesion has a fruity odor when exposed. Decline may be sudden and tree death can occur.	Phytophthora canker (many *Phytophthora* spp.)	Attacks phloem tissue of lower trunks of deciduous fruit and nut trees. As with all *Phytophthora* spp., disease is favored by excess soil moisture, such as occurs with overirrigation or poor drainage. Fungus can be spread on contaminated nursery stock, irrigation water, and cultivation equipment. Use sanitation measures. Do not allow the lower trunks of trees to stay wet because the high humidity favors infection. Drip emitters should be placed away from tree trunks and minisprinklers should be aimed to avoid wetting tree trunks. Also, avoid wounding the trunks during pruning. If cankers are detected at an early stage, they can sometimes be controlled by cutting out the infected tissue. Cankers can also be caused by bacteria, as discussed in this table.
Leaves turn yellow, red, or purple, and drop. Trees look drought stressed. Roots are destroyed. Bark of infected roots slides off easily when pinched. Symptoms appear similar to lesions or cankers, but may be difficult to distinguish from nematode, salt, or flood damage.	Phytophthora root rot	Caused by the same fungi (*Phytophthora* spp.) that cause crown rots, but they infect roots in causing this disease. Attacks deciduous fruit and nut trees. Called wet feet in the trade. Can occur when water is in direct contact with the base of the trunk and trunk is allowed to stay wet. Shorter, less frequent irrigations may help if damage is not severe. Avoid waterlogging soil. Use rootstocks tolerant to wet feet. Do not plant fruit and nut trees in the lawn, where watering is too frequent. If damage is severe, remove tree. Fungi can survive in soil for years. No fungus mycelia are visible, distinguishing this disease from Armillaria root rot.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Poor growth, loss of tree vigor. Small, yellowing leaves; premature leaf drop; wilting, collapse. In winter, *Armillaria* often forms clusters of mushrooms at base of infected trees a few days after a rain. White, fan-shaped fungus mycelia grow between bark and wood in crown region. Decayed bark has mushroom odor.	Armillaria root rot *(Armillaria mellea)*	Also known as oak root fungus and shoestring root rot. Attacks apple, cherry, almond, olive, peach, prune, plum, apricot, and kiwifruit, all of which are highly susceptible. Pear, fig, persimmon, and black walnut are comparatively resistant. Visible symptoms may not appear until fungus is well established. Normally kills the lower trunk cambium layer, girdling the tree, and can destroy entire root system. Once symptoms appear, it is very difficult to save a tree, and disease may have spread to roots of adjacent trees. After aerial parts of infected trees are gone, the fungus remains alive in the roots, ready to infect any replanted susceptible trees, such as citrus, avocado, or any of the susceptible deciduous fruit and nut trees listed above. Use resistant rootstocks, if available; for example, Marianna 2624 and certain selections of Myrobalan Plum exhibit resistance. Let soil dry out between irrigations. Once established, this disease is difficult to eradicate. It may survive for many years in the soil. Therefore, fumigate before replanting.
Dark olive green to black spots on foliage blossoms and fruit. Fruit spots later become scablike. Twisted, puckered leaves have black, circular, scabby spots on upper surfaces. Spots velvety on leaf undersides. Infected fruit become distorted and crack, allowing entry of secondary organisms. Young fruit may drop.	apple scab *(Venturia inaequalis)* pear scab *(Venturia pirina)*	Attacks apples, pears, and other pome fruits. The most serious disease of apples in California. Causes loss or severe surface fruit blemishing. Occurrence is most severe in northern and coastal areas of California, where spring weather is cool and moist. Fungus overwinters in dead leaves on the ground. Spores are released during spring rains, landing on and infecting leaves, flowers, and fruit. New spores produced on infected leaf or fruit surfaces 10–20 days later, spreading disease. Infection occurs most rapidly from 55° to 75°F; leaves must remain wet continuously for several hours for infection to occur. Manage disease in the backyard by removing leaves beneath trees in winter. Fall foliar fertilizer (urea) applications hasten leaf fall and decomposition and help reduce spore numbers in following spring. Operate sprinklers between sundown and noon to allow adequate leaf drying before significant infection can occur. Synthetic fungicides and wettable sulfur are also effective treatments. See UC IPM Pest Note *Apple and Pear Scab* (Giraud et al. 2011).
Sudden limb death during summer heat. Rough, dark cankers at pruning wounds. Gum may ooze from edge of cankers. Fungus gains entry via pruning wounds.	Eutypa dieback of apricot (*Eutypa lata*, formerly *Cytosporina* spp.)	Attacks apricots. Cankers can spread 6 in per year. Fungus may reach trunk if affected branches not removed. Summer-prune trees when risk of rain is minimal (Jul–Sep). Remove infected limbs, cutting at least 6 in below discolored area.
Distorted, reddened leaves visible in spring; later fall off. Leaves thickened, puckered, causing them to curl. Fruit production is reduced if disease is severe.	leaf curl *(Taphrina deformans)*	Attacks leaves, shoots, and fruit of nectarines and peaches. Common problem for backyard gardeners. Fungus overwinters underneath bud scales and other protected spots as conidia (resting fungal spores). In the spring, conidia are moved by splashing water to newly developing leaves, where infection occurs. A preventive fungicide treatment is necessary every autumn after leaves have fallen to prevent leaf curl. If timed properly, a single fall treatment of copper-based fungicide can prevent leaf curl and shot hole disease. If trees have shown symptoms in the spring, be sure to treat the following fall to prevent more serious losses the next year. In areas of high rainfall, a second treatment in the late winter when buds begin to swell but before any green color appears may be advisable. Although symptoms of leaf curl will be seen primarily as new leaves develop, the disease is difficult to control at this time.
Small, round, purplish spots on leaves and fruit enlarge to about 1/4 in. Centers of leaf spots turn brown. Dark specks at centers of brown spots (fungus spores) visible only with hand lens. Centers of brown spots fall out, so leaves have "shot holes." Affected fruit become scabby.	shot hole disease *(Stigmina carpophila)* *(Coryneum beijerinckii)*	Also known as coryneum blight. Attacks almonds, apricots, peaches, nectarines, and cherries. Rare on peaches and nectarines. Does not cause holes in leaves, but gumming of small twigs. Fungus survives winter on infected buds, twigs. Rain or overhead irrigation spreads fungus spores to young leaves, twigs, buds, and blossoms, where they can cause infection if given 24 hours continuous wetness. Wind carries water-splashed spores. Buds and twigs affected in peaches, nectarines, and almonds. Leaves and fruit affected in apricots. Practice good sanitation. Remove and destroy infected twigs, buds, blossoms, and fruit when symptoms appear. Protectant copper-based fungicides in the fall, pink bud stage, and full bloom may be needed if disease incidence has been high.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Leaves suddenly wilt on one part of tree or on the entire tree and then turn brown and die but do not drop off for months. Brown to gray-brown streaks are visible in wood of branches or roots (plugged-up xylem tissues).	Verticillium wilt (*Verticillium* spp.)	Also known as vascular wilt. Attacks many deciduous fruit and nut trees, including almond, olive, pistachio, stone fruits, pome fruits, walnut, and persimmon. Many stone fruits used as rootstocks are susceptible. A soil fungus that enters the roots and moves upward, attacking and plugging up the water-conducting tissues (xylem). May kill the entire tree or only part of it, with the remainder having complete recovery. Do not plant fruit and nut trees on soil previously used for other susceptible crops. If disease is severe or recurs, removal of soil and all roots is the only solution.
Light-colored powdery spore growth on shoots, both sides of leaves, and sometimes flowers. Fruit may develop weblike, russeted scars. New growth is dwarfed, distorted, and covered with white powdery substance.	powdery mildew	Attacks many deciduous fruit and nut trees. Fungus species depends on crop attacked: *Podosphaera leucotricha* on apple, quince, pear, almond; *Podosphaera oxycanthae* on leaves/shoots of cherry, peach, plum; *Sphaerotheca pannosa* on leaves/fruit of apricot, peach, plum, rose. Powdery mildew survives from one season to the next in infected buds or as fruiting bodies on the bark of stems and trunks. Fungus spores (in chains) can be seen with a hand lens. Does not require high humidity, unlike most other fungi. Moderate temperatures and shady conditions are generally the most favorable for powdery mildew. In most cases, planting resistant cultivars and following good cultural practices will control powdery mildew. Plant in full sun, provide adequate irrigation, and avoid excess fertilizer. Fungicide applications are often needed on highly susceptible crops, such as apples. Wettable sulfur works well. Monitor the orchard and prune out infected tissues. See UC IPM Pest Note *Powdery Mildew on Fruits and Berries* (Gubler and Koike 2011).
Browning and withering of blossoms; blossoms, associated twigs, and leaves shrivel and die. Gummy ooze at base of dead flower. In humid weather, shriveled petals bear tiny grayish brown masses (fungus spores), which spread disease. Cankers (sunken brown areas) may develop around twigs at base of infected flowers, causing leaves at tips of twigs to shrivel up. After harvest, ripe fruit can also develop brown rot fruit rot on the tree or in storage. The rot spreads rapidly with the initial brown or tan spots developing gray to tan tufts of spores within a day or so.	brown rot of stone fruits (*Monilinia* spp.)	Attacks almond, apricot, peach, plum, cherry, nectarine, and quince. One of the most common and serious blossom and fruit diseases. Causes withering of flowers and girdling of twigs. Fungus survives the winter on diseased twigs and mummies (old, rotted fruits) on the ground or in the tree. In spring, spores are spread by air currents, rain splash, and insects. Spores infect flowers of the new year's crop. Prompt removal and destruction of diseased plant parts prevent the buildup of brown rot inoculum in isolated trees or small orchards and may be sufficient to keep brown rot below damaging levels. Prune trees from the time they are planted to allow good ventilation in the canopy. Avoid wetting blossoms, foliage, and fruit during irrigation. When possible, plant cultivars less susceptible to brown rot. After leaves drop but before the first fall rains, remove all fruit and nut mummies and prune out branches with diseased twigs. Destroy mummies and prunings by burning, burying, or bagging. During the bloom period and as fruit begin to ripen, check trees for brown rot symptoms. Remove and destroy all diseased tissue. After harvest, remove all fruit and nuts left on trees and destroy them because they are potential overwintering sites for brown rot and other pests. If inoculum builds up, a protectant fungicide application may be needed to prevent serious loss. Sprays must be applied before each spring rain to be effective.
Bark and wood develop localized dead areas near pruning wounds or other injuries. Branches become girdled; leaves wither.	Phomopsis canker of fig *(Phomopsis cinerascens)*	Attacks fig. Kadota and Calimyrna cultivars most susceptible. Mission rarely attacked. Prune late in dormant season. Remove diseased branches from orchard and burn them. Fungus survives in cankers in trees or dead wood in surrounding areas.
Diseases caused by bacteria and mycoplasmalike organisms (MLO)		
Young blossoms, shoots, and fruit wilt and collapse, turning brown to black. Sticky brown ooze appears on diseased shoots during humid weather. Cankers appear on limbs and secrete dark ooze in spring. Entire branches or tree can die in one season.	fire blight of pome fruits *(Erwinia amylovora)*	Attacks pear, apple, and quince. Blossoms and succulent shoots are most susceptible. Bacterium survives in cankers; spread by splashing rain and insects. Favored by warm, humid weather during bloom. Cut diseased branches back about 12 in into healthy wood, removing all diseased tissue. Avoid planting susceptible rootstocks such as M-26. Sterilize pruning tools in household disinfectants before making each cut. Apply diluted copper fungicides during bloom period as preventive sprays. See UC IPM Pest Note *Fire Blight* (Teviotdale 2011).

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Bacterial canker: Irregularly-shaped brown water-soaked or gum-soaked areas develop in bark and outer sapwood of spurs, branches, and sometimes trunk. Small cankers can develop on twigs at base of infected buds. When trees begin active growth in spring, amber-colored gum may exude from canker margins. Cankers are darker than healthy bark. Underlying diseased tissue is reddish brown, moist, and sour smelling. *Bacterial blast*: Blossoms "blasted" (blighted), turn brown, shrivel, cling to trees. Dark brown or black spots on leaves, fruit. Leaves drop. Symptoms on apple and pear similar to fire blight, but blast does not extend as far down the shoot from the tip, and blast does not produce ooze. Bark of infected twigs is tan and papery.	bacterial canker, bacterial blast *(Pseudomonas syringae)*	Also known as gummosis. Attacks almond, cherry, peach, nectarine, apricot, plum, apple, pear, and kiwifruit. Bacterial cankers develop during the dormant season and early spring and occur primarily on stone fruit trees. Bacterial blast or blight of buds, blossoms, leaves, green shoots, and green fruit can occur on pome and stone fruits in wet, cold spring weather. Under favorable conditions, bacteria enter via buds, leaf scars, wounds, and natural openings (leaf or branch pores). Infections occur in fall, winter, and early spring. Canker growth ceases in summer, may resume in fall. Damage from bacterial canker and blast can be minimized by cultural practices. Losses can be reduced by selecting resistant rootstocks, avoiding planting on shallow soil, providing adequate nutrition (particularly nitrogen), and protecting trees from freezing temperature during bloom or early fruit growth by covering them or providing protective shelters. In California, feeding by high populations of ring nematodes is thought to be the most important factor making almonds and stone fruit trees susceptible to bacterial canker. Select planting site carefully. Trees receiving adequate nitrogen fertilizer recover better from bacterial canker infection. If trees are damaged, remove entire affected branches in the summer, being sure to eliminate entire canker and a few inches below.
Walnut hull has rough, sunken, hard, blackened areas. If young nuts affected, they drop prematurely. Older nut kernels turn black and shrivel. Infected florets first appear water soaked and wilted, later turn black.	blight of English walnut *(Xanthomonas campestris)*	Attacks English walnuts. Bacteria overwinter in buds, twig lesions, and old nuts. They infect catkins, fruit, green shoots, leaves, and buds. Bacteria are spread by rain splash. Disease is worse in early-leafing cultivars. Black walnut species seldom affected. On susceptible cultivars, avoid wetting foliage with sprinklers. Avoid irrigation during bloom. Prune trees for better air circulation. Fruit may become infected at any time after formation until harvest. This long susceptibility period is one of the chief obstacles to disease control. Specific fertilization or cultivation practices offer little control for walnut blight. Planting late-blooming cultivars can be beneficial. One to three fixed copper spray treatments are the most effective control. The first application should be made no later than the first appearance of the pistillate bloom.
Cherries fail to ripen, are conical, tasteless, and tan colored. Leaves in midsummer are yellow. One or a few limbs may be affected. On peach, leaves turn yellow; tree declines; small shoots die.	X-disease of cherry	Also known as buckskin disease. Attacks sweet and sour cherry. Caused by an MLO. Leafhoppers transmit the pathogen. Trees on Mahaleb rootstock may die within weeks as if girdled. Remove infected limbs or trees. Practice good sanitation.
Crown galls (rough, warty tumors caused by this soil-dwelling bacterium) first appear as smooth swellings.	crown gall *(Agrobacterium tumefaciens)*	Attacks pome fruits, stone fruits (including almonds), and walnuts. Most damaging to young trees and vines. Obtain good-quality material from a reputable nursery and use careful planting and pruning techniques. Can survive in soil for at least 2 years without host tissue. Established trees and vines are infected only through fresh wounds such as those caused by growth cracks, pruning, cultivation equipment, or freezing injury. Seedlings may be infected during germination. Bacteria are released into soil when galls are wet or when older gall tissue disintegrates. On trees, galls develop on large roots at the crown. Larger trees and vines can usually tolerate galls. Younger trees affected. Treat by applying bactericide in dormant season, spring, or early summer. Rinse soil away from galls and allow to dry thoroughly before treating.
Disease caused by virus		
Poor terminal growth; yellowing; premature defoliation; tree stunted, eventually dies. Small holes, cracks in bark at graft union.	blackline virus	Also known as cherry leafroll virus. Attacks walnut. No known cure. Remove affected trees to protect adjacent healthy trees. Virus transmitted by grafting and infected pollen. When bark is removed, horizontal black line is visible at the graft union. All English walnut on black walnut rootstocks are believed susceptible.
Physiological (abiotic) disorders		
Pit-burning of apricot. Inner mesocarp of ripe apricots becomes brown, gelatinous.	air temperatures of 104°F for a few days	Green, immature apricots do not show this symptom when exposed to these same high temperatures for an equivalent period of time. Disorder is attributed to lack of oxygen in inner mesocarp resulting from high respiration rates due to heat stress. Select cultivars that do not pit-burn easily.

Table 16.6. cont.

SELECTED PROBLEM DIAGNOSES IN TEMPERATE TREE FRUIT AND NUT CROPS

What the problem looks like	Probable cause	Comments
Blackening of peach. Portions of flesh of ripening peaches becomes grayish black.	air temperatures of 102°F for a few days	Discoloration is easier to detect in white-fleshed cultivars. Darkening is worse near the pit, suggesting that oxygen supply is insufficient there. Oxygen used by heat-stressed fruit cells for respiration cannot be replenished fast enough.
Internal browning of prune. Flesh turns brown or black instead of amber.	high temperatures	Discoloration is worse near the pit and is related to lack of oxygen there.
Premature shriveling of prune. Prunes turn blue and shrivel.	hot, dry winds	High winds cause an increase in the transpiration rate, and tree cannot supply fruit with sufficient water. Disorder is attributed to both heat and water stress.
Water core of apple and pear. Core zones have glazed, water-soaked appearance.	temperature stress, including temperature gradient; overmaturity	A temperature gradient–related disorder. Asian pears are more susceptible than European pears. Highly pigmented red apple cultivars are more susceptible than yellow- or green-skinned cultivars because darker skin absorbs more heat.
Pink calyx of pear. Calyx of Bartlett pear turns pink.	low temperature of 68°F 4–6 weeks before harvest	These fruits soften rapidly after harvest.
Black kernel of walnut. Kernel shrivels, darkens, becomes worthless.	sunburn	Nuts are at risk from sunburn because they are borne terminally on spurs. Heat from sunburn is transmitted to the kernel. Spraying whitewash does not lower fruit temperature enough to prevent sunburn.
Bud failure of almond. Vegetative buds abscise; buds that remain go dormant or grow vigorously. Sparse growth on some parts of tree; vigorous growth on other parts. Called crazy top or witches'-broom due to appearance.	high summer temperatures	All cultivars are susceptible. Appears sporadically in the whole tree or parts of a tree after exposure to extremely high summer temperatures. Symptoms get worse after each heat spell.
Cracking of sweet cherry fruit.	rain	Droplets of water left on ripe fruit cause them to split because water penetrates mesocarp faster than the epidermal cells can expand.
End-cracking of prune. Bottom end of fruit crack in Jun. Cracking of apple skin. Skin cracks on fruit, particularly on side of tree that gets most sun.	water stress followed by irrigation	Prunes: Appears on trees irrigated after water stress. Mesocarp separates from endocarp when fruit regains turgidity due to water uptake. Apples: Apple skin loses elasticity from heat stress due to sun; subsequent uptake of water by fruit cells after irrigation leads to cracking. Irrigate when soil is still somewhat moist. Prune and fertilize to maintain full canopy.
Side-cracking of prune. Sides of fruit crack in Jul.	excess water uptake	Appears on fruit exposed to direct sunlight and cool night temperatures such that dew forms. Mesocarp cells take up water, become turgid; epicarp and mesocarp crack. Mesocarp cells of immature prunes can become meristematic, forming ugly callus tissue. When ripe prunes crack, sugars and gums are exuded that can support mold growth. Some molds can produce carcinogenic aflatoxins.
Russeting of apple and pear. Brown corky layers on epidermis due to moisture condensation or "frost rings."	moisture condensation, frost, or pesticide sprays	Fog, dew, and spray droplets that do not dry rapidly lead to this problem, especially in coastal California. Cover fruit with bags to avoid condensation on fruit skin in areas of morning fog. Young apple and pear fruit can develop "frost rings," a type of russeting. Cortical tissue growth is inhibited.
Splitting of the endocarp. Split pits on peaches, nectarines, almonds, plums, sweet cherries, olives.	growth-related disorder (stress between mesocarp and endocarp)	Prevalent in early-ripening peach and nectarine cultivars. Do not thin crop just prior to the pit-hardening growth phase. Do not irrigate immediately after thinning. Cultural operations that favor fruit growth during pit hardening cause a sudden surge of water and/or carbohydrates into mesocarp cells, increasing their turgor pressure.
Gumming. Leaves, fruit of stone fruits exude gums, mucilages onto epidermis. Ugly gum pockets on skin.	growth disorder	Gums and mucilages are complex carbohydrates synthesized by the leaves and fruit of stone fruits. They create internal pressure in mesocarp cells and diffuse to fruit surface. Fruits may abscise early or become culls at harvest.
Bitter pit of apple. Necrotic spots appear on fruit before or after harvest.	leaf-to-fruit ratio too large; poor pollination; frost damage during bloom	When crop is light, shoot growth outcompetes fruit for calcium. This large transpiring area draws calcium into foliage rather than into fruit. Fruit are calcium deficient. As a result, they respire more rapidly and have shorter shelf life. Summer pruning reduces incidence of bitter pit by regulating the leaf-to-fruit ratio, which means that less calcium is diverted to leaves. Control is achieved by spraying the trees with a calcium-containing fertilizer such as calcium nitrate with two to four applications starting when fruit are very small.
Wilting and shriveling of fruit.	premature harvest	Even if fruit are put into refrigerated storage at the proper relative humidity, if they are harvested when still immature, they will shrivel and wilt because their soluble solids content is too low and they are less capable of preventing water loss than mature fruit.

selection, and fertilizer and water management practices.

Fungi that infect the trunk and roots, especially feeder roots, which have critical roles in water and nutrient uptake, are important in California. Due to the state's semiarid climate, fungi that attack fruits are less damaging here than in other regions where temperate tree fruits and nuts are grown. Many diseases are described according to the plant part(s) they damage. For example, *Phytophthora* spp. fungi cause a number of diseases whose names depend on the part of the tree affected—roots (Phytophthora root rot), trunk (crown rot or collar rot), or fruit (brown rot of citrus).

In addition to Phytophthora root rot, one other root disease commonly affects temperate fruit tree roots in California: oak root fungus (Armillaria root rot), which attacks many crops, including almond, apple, apricot, pear, plum, prune, and walnut. Phytophthora destroys feeder roots and no mycelia are visible; Armillaria also moves into the wood (xylem) of the root and crown, and fan-shaped mycelia are visible (see table 16.6).

Prevention is the most important and economical method of controlling diseases. Preventive measures can include use of tolerant rootstocks (see the section "Cultivars" in this chapter), preplant soil preparation, good drainage, judicious irrigation management and sanitation, and adequate fertilization. Staff at reputable nurseries and your local UC Cooperative Extension farm advisor are familiar with the most important diseases in your area and know which scion-rootstock combinations are most tolerant and vigorous. Trees can also be planted on a mound or berm to improve drainage around the crown and root system (see fig. 16.33).

Environmental stresses, such as nutrient deficiencies or adverse weather and soil conditions (excessive or too little irrigation water, poor drainage), may cause symptoms described as abiotic disorders. Symptoms associated with several environmental stresses and physiological disorders and a few comments on managing them are included in table 16.6.

Control Measures

Whenever possible, combat pests with mechanical control methods (remove diseased limbs, clean up debris, dislodge pests with strong blasts of water, soap, or oil sprays) and biological control methods (release natural enemies). Use chemical pesticides as a last resort. Unlike commercial growers, home gardeners are not faced with the same economic demands for fruit appearance, so they can tolerate more damage. Chemical controls kill the target pests but may also kill the biological enemies naturally present or introduced into the garden. See chapter 9, "Safe and Sustainable Pest Management," for additional information. For the most recent pesticide recommendations, consult the UC IPM website, ipm.ucdavis.edu, and your UC Cooperative Extension county office.

Mechanical control of insect and mite pests

Mechanical methods are nonpolluting, nonpersistent pest control techniques that are effective against a number of insect and mite pests. For example, strong blasts of water usually dislodge aphids, and handpicking snails and slugs is effective in small gardens. Sanitation, the removal of diseased or insect-infested leaves and fruit, is an excellent mechanical means of reducing pest problems.

Organic materials and biological agents

The definition of organic materials was developed by various certification groups and officially adopted by the state and federal governments. These materials are usually natural products that have not been significantly modified by people. They include various mineral products (copper and sulfur for disease control) and soaps and oil sprays (mostly for control of soft-bodied insects and mites). To avoid damage to your trees, use soaps, oils, and sulfur sprays only when the trees have been well irrigated and when the temperature is cooler than 90°F.

Soaps are moderately effective on contact against soft-bodied insects and mites. They penetrate pest cell membranes and kill without harming trees or fruit. Apply soaps in the early morning or late afternoon. Insecticidal soaps can be purchased or made at home by using 2 tablespoons of liquid dishwashing soap per gallon of water, but be aware that some soaps are phytotoxic. Repeated applications may be necessary; be willing to accept some injury to trees or fruit.

Horticultural oils smother and kill soft-bodied insects and mites. Summer oils are identified as supreme, superior, or narrow range on the label. Horticultural oils were originally applied to deciduous plants during the dormant season (dormant oil), and even though they now may list application rates for use during the growing season, they are formulated differently from true summer oils. Do not apply oil mixed with sulfur within 2 weeks of an application of sulfur onto nondormant trees. Do not apply oil to dry trees; wait for a good rain or irrigate dry soil prior to application.

Sulfur is a very effective natural mineral that controls eriophyid mites, powdery mildew, apple and pear scab, and peach leaf curl. Unfortunately it kills some beneficials. It comes in several forms: dust, wettable powder, micronized wettable powder, and mixed with lime in a liquid form called lime sulfur. Do not apply a mixture of oil and sulfur onto green leaves, blossoms, or fruit. Lime sulfur and oil can be applied to dormant trees. Sulfur is an irritant; wear protective clothing during application and protect the skin and eyes.

Copper is another naturally occurring mineral that is extensively used in organic agriculture. The primary form, copper sulfate ($CuSO_4$), or fixed copper, is mixed with hydrated lime in order to fix the copper and form copper hydroxide or oxidized to form copper oxide. It is used for the prevention of root and crown rot, apple and pear scab, peach leaf curl, shot hole fungus, brown rot, fire blight, bacterial canker, and walnut blight with varying degrees of success depending on the disease, timing, and rates applied. As with all pesticides, wear protective clothing during the application.

Biological control agents such as predatory and parasitic insects and antagonistic disease organisms used to control pests do not usually control problems as quickly as conventional pesticides do. With many of these methods, home gardeners must be patient and must expect long-term results with some immediate damage. Biological control of insect and mite pests is generally more effective in coastal regions than in the Central Valley or the southern desert valleys because the cooler temperatures help prolong the life of most organisms. UC scientists are actively engaged in detecting and importing biocontrol agents of major pests of crops important in California agriculture. A number of biological control agents effective against pests of temperate fruit and nut trees are native to California. When native California parasites and predators are not available, UC entomologists travel to the areas of the world where many pest species are believed to have originated to search for the pests' natural predators and parasites. If a particular parasite or predator looks promising, UC scientists bring it back to California with the appropriate permits and place it into UC quarantine facilities to undergo intensive research. UC entomologists release the imported biological control agents into the environment only after research results document their effectiveness and safety.

Conventional pesticides

Pesticides that kill or prevent damage from pests are commonly used on fruit trees; in some cases, there is no other effective or practical control method. Great care must be taken when using conventional pesticides, since they are toxic substances that can harm nontarget beneficial organisms or pollute the environment if not used properly. In most cases, they should be used only as a last resort. Misuse is the most common reason for problems associ-

ated with pesticides. Read the label carefully prior to use and follow all labeled instructions and restrictions. For more information on using pesticides safely and effectively in the home garden, see chapter 9, "Safe and Sustainable Pest Management."

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Citrus 17

Deborah Silva, Carol Lovatt, Mikeal Roose, and Georgios Vidalakis

Learning Objectives

Become acquainted with the history of citrus in California.

Become familiar with citrus cultivars that do well in the home garden in various climate zones in California.

Learn the basic cultural requirements of citrus trees.

Learn some basic principles of pest and disease management of citrus.

Citrus

Citrus is one of the crops that was an essential part of the development of California agriculture and the horticultural research programs at the University of California (UC). Worldwide, more fruit is produced by citrus trees than by all the deciduous fruit trees (e.g., apples, peaches, pears) combined. Home gardeners in California can grow edible or ornamental citrus cultivars as standard-sized trees (trees that grow to the size typical of the cultivar), as semidwarfs (trees that attain about two-thirds of standard size), or as dwarfs (trees that attain about half the standard height). For any one specific citrus type, the fruit will be the same size regardless of whether the trees are dwarf, semidwarf, or standard size. Home gardeners can plant citrus trees in the yard, in pots on the patio, or as espaliers along a fence or wall. They can choose commercially successful cultivars or cultivars that lack commercial interest but have appeal to the home garden trade.

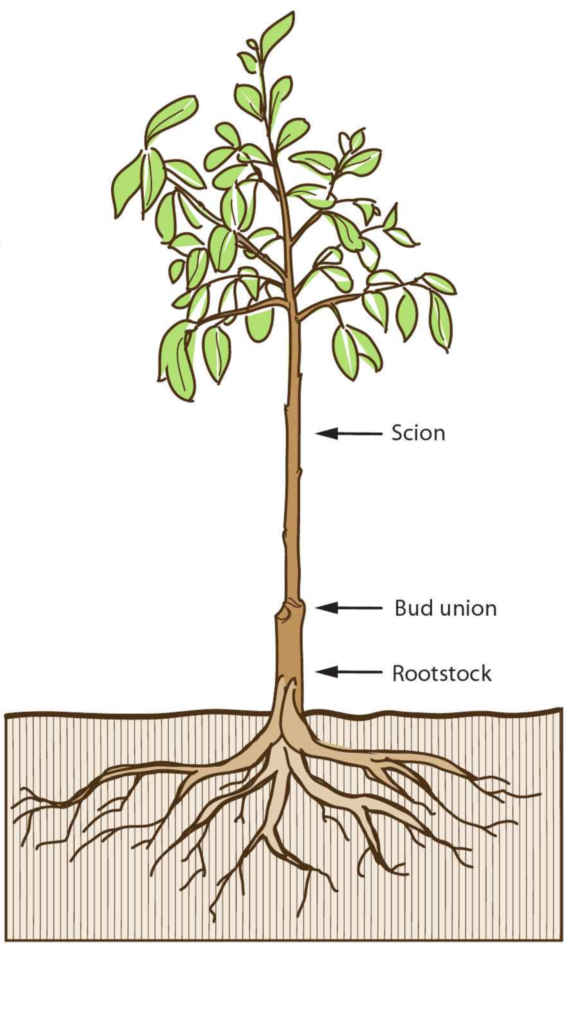


Figure 17.1

A cultivated citrus tree is two joined parts that originated as two separate trees. The top portion, known as the scion, is the fruiting cultivar, which is grafted onto a rootstock. The bud union is the point at which the scion joins the rootstock. *Source:* After Citrus 1996, p. 31.

Citrus trees available today, whether dwarf, semidwarf, or standard size, are the products of considerable scientific research. They usually consist of a scion-rootstock combination in which the rootstock provides the lower 6 to 18 inches of the trunk and the tree's roots, and the scion provides the major portion of the trunk, all branches, leaves, flowers, and fruit (fig. 17.1). Scion cultivars are usually grafted onto rootstocks selected for improved disease resistance, cold hardiness, productivity (yield), favorable effects on fruit quality, and other desirable traits, such as dwarfing characteristics. By grafting mature fruiting wood onto a selected rootstock, the tree begins fruiting in a few years, rather than in the 10 to 15 years that would be required for a tree grown from a seed. Seedling trees must pass through a lengthy juvenile phase of growth before they become mature enough (competent) to flower and bear fruit.

History of Citrus in California

Citrus has a rich heritage in California. Believed to be a native of China, citrus, over the centuries, has traveled the routes of conquerors and missionaries. None of the citrus species grown in California is indigenous to the New World. Citrus was introduced into California in 1769, when the Spanish missionary and Franciscan priest Father Junipero Serra planted oranges and lemons at Mission San Diego. In 1841, William Wolfskill planted the first commercial citrus grove in Los Angeles. In 1856, Judge Joseph Lewis planted the first citrus trees in northern California. The Mother Orange in Oroville, one of the judge's original trees, is the oldest citrus tree in the state. By 1867, the United States Department of Agriculture (USDA) reported that 17,000 orange trees and 3,700 lemon trees were growing in California, primarily in the Los Angeles area.

Navel Oranges

Navel oranges, which were to become famous as California "eating oranges," were planted in Riverside by Eliza and Luther Tibbets in 1873. The Tibbetses had been given two branches of a new, untested orange cultivar from Brazil that was fresh out of quarantine in Washington, D.C. The orange was named the Washington navel in honor of its domestic source, Washington, D.C., and in recognition of its "belly button" base.

The trees that the USDA shipped to Riverside started bearing fruit in 1878, and their quality as eating oranges was superior to any cultivar previously grown in California. The navel orange is distinct from the juice orange because the former does not have seed and comes apart in neat sections, making it a superior eating orange. In addition, its thicker, easily peeled skin not only protects the delectable fruit sections but also allows for shipping to distant markets.

Riverside has an ideal climate for growing navels, and citrus culture (citriculture) literally changed southern California's landscape as groves spread across Riverside, San Bernardino, Orange, Los Angeles, and Ventura Counties. Today, one of the two original trees planted by the Tibbetses, known as the Parent Navel Orange tree, still grows and bears fruit in Riverside.

Commercial Expansion

Transcontinental railroads opened up the rest of the country to California's commercial citrus harvest in the 1870s and 1880s. In 1887, the first cold-storage shipment of Riverside navels was sold on the floor of a Boston exchange. During this period, northern groves were also bearing fruit in Porterville, Sacramento, and Marysville.

In the 1890s, cooperative citrus exchanges were established to promote and cooperatively market the increasing production. The Southern California Fruit Exchange, established in 1893, was incorporated in 1905 as the California Fruit Growers Exchange to recognize the inclusion of northern growers. The exchange advertised fresh California citrus aggressively to Midwestern and Eastern states, advertising citrus as a "warm ray of California sunshine." The exchange pioneered packing and shipping technologies and advertising techniques critical to the growth and development of the California citrus industry. Today it is known as Sunkist Growers, Inc., and represents California and Arizona citrus growers.

Citrus Industry Today

The locations of some of California's major citrus production areas have shifted because of the pressures of urbanization, high cost of land, and disease problems, but citrus research at UC and fruit productivity are thriving. Today, California and Arizona are the major producers of fresh citrus fruit in the United States, and Florida is the major producer of juice and processed products. California produces

80% of the nation's lemons. The farm gate value of California fresh citrus was $1.5 billion for 2012–13 (NASS 2010). The total annual value of California citrus often establishes it among the top 10 crops in the state.

For more information on the history of citrus in California, see the following references listed in the bibliography at the end of this chapter: UC's *Citrus Production Manual* (Ferguson and Grafton-Cardwell 2014); UC Riverside Citrus Variety Collection website (citruscultivar.ucr.edu); *The Citrus Industry* (Reuther, Batchelor, and Webber 1967–1989); *Citrus: Complete Guide to Selecting and Growing More than 100 Cultivars for California, Arizona, Texas, the Gulf Coast, and Florida* (Walheim 1996); *Citrus Cultivars of the World* (Saunt 2000); and *Citrus* (Sunset-Publishing 1996).

University of California Experiment Station and Related Citrus Resources

The University of California established the Citrus Experiment Station at Riverside on February 14, 1907, preceding the UC campus at Riverside by about half a century. (The experiment station is now known as the Citrus Research Center and Agricultural Experiment Station.) The selection of Riverside was preceded and followed by bitter battles among the competing southern California citrus interests who desperately wanted the coveted UC facility in their city.

In less than a decade, the Riverside facility achieved recognition as the world's outstanding research institution on citrus and subtropical horticulture. By June 1917, numerous experiments were established at the station, including studies in cultivation, scion–rootstock compatibility, fertilization, and the Citrus Variety Collection, containing more than 1,000 types of citrus from all over the world. New fruiting cultivars of mandarins (Kinnow, Gold Nugget, Pixie, Shasta Gold, Tahoe Gold, Tango, Yosemite Gold), oranges (Trovita), and grapefruit (Melogold, Oroblanco) have been released over the years from the citrus breeding program at UC Riverside (UCR). Many citrus pests and diseases are held in check by the management strategies developed by UC entomologists, plant pathologists, and nematologists. The pioneering studies on irrigation management, mineral nutrition, pruning techniques, use of plant growth regulators (hormones), pest and disease control, and postharvest handling have influenced practices in citrus orchards not only in California, but worldwide.

Today, research facilities at UC Riverside include the

- National Citrus Clonal Germplasm Repository, funded by the USDA's Agricultural Research Service (ARS)
- Citrus Variety Collection, www.citrusvariety.ucr.edu, which is a living museum of more than 1,000 different types of citrus
- Citrus Clonal Protection Program (CCPP, www.ccpp.ucr.edu), which provides pathogen-tested citrus budwood to nurseries and other interested parties for reproduction

In addition to the academic resources devoted to citrus, California State Parks operates the California Citrus State Historic Park in Riverside, which has two goals: to preserve the vanishing cultural landscape of the citrus industry and to tell the story of the citrus industry's role in the history of California. The park includes an interpretive center and tours of demonstration groves that continue to produce high-quality citrus fruit of many cultivars.

Citrus Growth and Development

Unlike annual vegetable crops, in which the focus is a single season's harvest, fruit trees such as citrus are perennials. The gardener's attention must be on the current season's harvest as well as on long-term care to maintain tree health and vigor for many years. Citrus trees are evergreen and drop their leaves through-

out the year, a few at a time, not all at once in the fall as is typical of deciduous fruit trees such as apple and pear. In the first 3 or 4 years after planting, both evergreen and deciduous fruit tree types are nonbearing (fruit production is absent or light) and both types have seasonal cycles during the year. However, evergreen fruit tree growth and development is different from that of deciduous fruit trees, and the trees require different care. One important exception is trifoliate orange, a deciduous citrus tree relative. However, since trifoliate orange is used only as a rootstock in the citrus belt, its deciduous growth habit does not affect the evergreen nature of the scion canopy.

Roots

The first year that a citrus tree is in the ground is the most important for root development. Stresses caused by diseases, nematodes, weed competition, insufficient watering, or overwatering can hinder root and scion development. Citrus roots can extend up to twice as far as the drip line, that imaginary circle below the canopy edge. Gardeners should consider these facts when irrigating and fertilizing citrus.

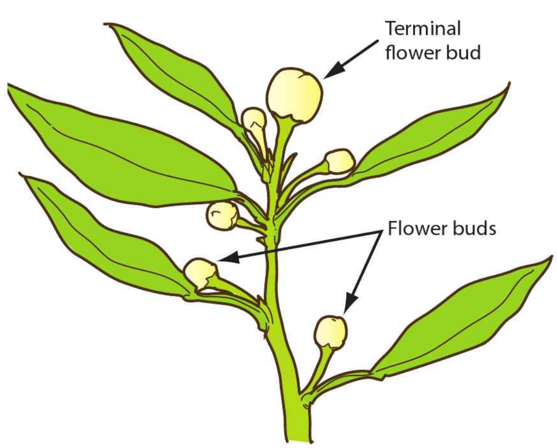
Leaves

Citrus trees have thick, leathery leaves whose function is more complex than leaves of deciduous fruit trees. In both fruit tree types, leaves engage in photosynthesis, but in citrus the evergreen leaves—along with twigs, branches, and roots—are also involved in storing excess photosynthate (food) through the winter. In citrus leaves, the maximum amount of food stored is in late February or early March, just before the spring bloom and growth flush; thus, pruning should not be done at this time of year because leaf loss would reduce subsequent fruit yield.

Leaves are arranged spirally on the stem and typically remain on the tree for 1 to 2 years. An axillary (lateral) bud grows in the axil of each citrus leaf. During the spring flowering period of most citrus types, leaf drop can be pronounced and new leaf growth is most vigorous. Environmental factors, such as high temperatures, wind, low soil moisture, low relative humidity, nutrient deficiencies, and high soil salinity, can cause premature leaf drop. Other causes are disease or pest problems and rootstock-scion incompatibility.

The leaves of some citrus species contain essential oils that are important ingredients in pharmaceutical products, perfumes, and condiments used in cooking.

Figure 17.2



Citrus flower buds form on new vegetative growth arising from older leafy stems. *Source:* After Reuther et al. vol. 2, 1968, p. 25.

Flowers and Fruits

Citrus flowers, which are white to purplish, are known for their alluring fragrance. Oils from the flowers of the sour orange *(Citrus aurantium)* cultivar Bouquet de Fleurs are used in perfumes, as are the oils of Bergamot citrus *(Citrus bergamia)*, which is grown in southern Europe. Nectar from citrus flowers is a favorite food of bees and is the raw ingredient of citrus-based honey.

After dormancy induced by low temperature in winter or drought, floral shoots form in dormant buds at the apex of shoots and in the axils of leaves on vegetative shoots that developed the previous spring, summer, and fall. In each bud, the vegetative apical meristem is transformed into a terminal flower bud at the apex of the developing floral shoot, which may

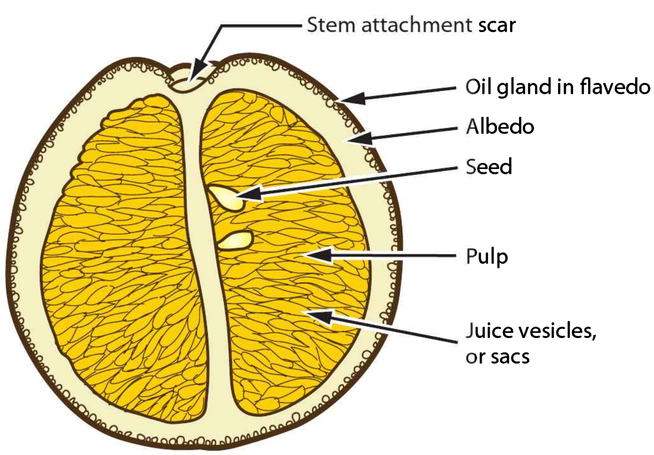
produce additional flowers and leaves at the nodes below the apex or remain a single apical flower (fig. 17.2). Thus, citrus can produce single terminal flowers, multi-flowered floral shoots without any leaves (leafless floral shoots, or leafless inflorescences), or leafy floral shoots (leafy inflorescences) with one to many flowers and one to many leaves. Citrus trees usually flower abundantly, but most flowers and young fruit are shed without setting fruit that survive to maturity. Citrus flowers are perfect, complete with male and female structures. Most citrus types are self-compatible, which means that they can be fertilized by their own pollen (self-pollinated) and can produce a crop even if a single tree is planted in isolation from other citrus trees. Unlike most citrus, Clementine mandarins, pummelos, and some grapefruit hybrids are self-incompatible, which means they cannot be fertilized by their own pollen. To set a large crop of fruit, these must be pollinated by another tree of the same species planted nearby. In contrast, parthenocarpy, development of the ovary into a mature fruit without pollination or fertilization, is common in citrus.

Citrus fruit are a type of berry known as a hesperidium. Scientists identify the parts of the fruit using precise terminology (fig. 17.3). Citrus fruit usually attain edible quality 8 to 16 months after bloom and have a variable harvest season of about 2 to 6 months, depending on climate. Only about one-fourth of the ascorbic acid (vitamin C) in citrus fruit is found in the juice. The remainder is in the peel, concentrated primarily in the flavedo, the outer colored portion (see fig. 17.3).

When a citrus fruit is of sexual origin, one of the two sperm cells in a pollen grain fertilizes the egg cell in the ovule, which then develops into an embryo (young citrus tree) within the seed (formerly the ovule), and the surrounding ovary develops and matures into the fruit (see fig. 17.3). However, the sex life of citrus and the development of its fruit often are more complex than many other crops in the home garden (see the section "Citrus Botany and the Importance of Nucellar Embryony," below).

Figure 17.3

Schematic of a section through a mature citrus fruit. The rind consists of the thin, pigmented flavedo and the thicker, white albedo.



Annual Growth

During the first 3 or 4 years after planting a citrus tree, fruit production is light; this period is known as the nonbearing years. Major root growth occurs during this period, and the framework of the tree is developing for fruit production. Bearing trees have a seasonal cycle that begins in the spring with the enlargement of flower buds that produce the current season's crop (see fig. 17.2). Early-opening inflorescences tend to be completely floral. The predominance of this type of inflorescence is referred to as a popcorn bloom. Flowers opening late in the bloom period tend to be on leafy floral shoots and produce more fruit that survive to harvest. Weather conditions, pests, or diseases that lead to blossom injury adversely affect the season's fruit production. Faster-growing ovaries tend to set fruit better and survive to harvest, whereas slower-growing fruit are more likely to drop at an early stage of development.

In California's subtropical climate, citrus trees usually have three vegetative

shoot growth flushes: in spring, summer, and fall. Each growth flush can produce flowers and set fruit, but in most cultivars, the spring flush is the most productive, followed by the summer flush. Flowering is typically restricted to spring, but some citrus cultivars flower more than once. After pollination and fertilization of flowers that bloomed during the spring growth flush, the citrus tree typically yields a single crop of fruit that matures as early as fall or as late as the following summer, depending on the cultivar. Citrus types that are everbearing in the coastal areas of California, such as lemons, limes, and citrons, can bloom and set fruit throughout the year, but they tend to bloom most abundantly in the spring.

Citrus trees grow best between 70° and 90°F. For this reason, the citrus belt lies between 35°N and 35°S latitude. The maximum northern latitude at which citrus is grown is in Spain at 44°N because of the modifying effects of the Canary current. The maximum northern latitude at which citrus is commercially grown in California is 39°N because of the modifying effect of the Japanese current. When temperatures reach 100°F or drop to 55°F, citrus trees reduce their growth rate and may appear to stop growing. Reduced growth in response to cold winter temperatures approaches dormancy, but citrus trees do not go dormant the way deciduous fruit trees do. During this period of reduced growth, trees maintain a basal rate of water transport and starch consumption.

Mature Tree Size

Mature tree size depends primarily on the fruiting cultivar (scion) and rootstock but is also affected by growing conditions and cultural practices. Mature, standard-sized orange and grapefruit trees are 20 feet and 30 feet tall, respectively. The only true genetic dwarf rootstock currently available is Flying Dragon trifoliate orange. On Flying Dragon rootstock, mature trees grow to less than half of standard size. Other rootstocks may have a dwarfing effect on mature tree size in certain fruiting cultivars; such trees may be labeled semidwarfs and can grow to about two-thirds the standard size. Because the nursery industry is not regulated in using the term *dwarf*, deal with a reputable firm when purchasing citrus because some trees labeled as dwarfs may attain standard size at maturity. Some scion trees on their own roots may be sold as dwarfs; therefore, attempt to find out which rootstock you are purchasing with the fruiting cultivar chosen.

Citrus Botany and the Importance of Nucellar Embryony

Not all scientists agree on the number of citrus species, but scientists do concur that their botany is complicated. In many kinds of plants, species within a genus will not interbreed, and if they do, the offspring (the hybrid cross) is sterile. But in citrus, interfertility is usual and common. Thus, sweet oranges *(Citrus sinensis)* have crossed successfully with mandarin oranges *(Citrus reticulata)* to yield tangors, and mandarin oranges have crossed with grapefruit *(Citrus paradisi)* to yield tangelos. Some botanists believe that the grapefruit itself is a hybrid cross between a pummelo *(Citrus grandis)* and a sweet orange, and there is evidence that the sweet orange originated with a cross between a mandarin orange and a pummelo. However, this ease of hybridization does not tell the complicated story of citrus botany. Not only do recognized citrus species hybridize, but also the offspring of these matings are able, after pollination but without fertilization, to produce seed that give rise to plants that are duplicates (clones) of the parent tree. Thus, not all citrus seeds and trees are of sexual origin.

Many of the citrus cultivars you can grow in the garden produce two types of embryos in the same seed, a condition known as polyembryony: a sexual embryo

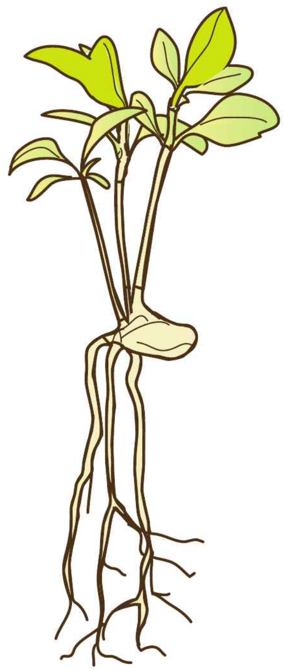


Figure 17.4

Polyembryony in a citrus seed indicated by multiple seedlings. Usually the weakest seeding is sexual and the others, nucellar.

develops after fertilization, and one or more asexual embryos arise from female nucellar tissue within the same ovule. The extra, asexual embryos that derive from cells of the nucellus (from the mother only) are known as nucellar embryos. Nucellar embryos are common in cultivars of the genera *Citrus* (oranges, grapefruit, lemons, mandarins), *Fortunella* (kumquat), and *Poncirus* (trifoliate orange). The stimulation of pollination is required for the nucellar embryos to develop. Nucellar embryos often crowd out the sexual embryo. Because nucellar embryos develop asexually from tissues of the female parent without any input from a male parent, they are genetically identical to (are clones of) the female parent, which is of practical importance in citrus breeding, particularly in producing clonal propagating material, such as clonal rootstocks. Nucellar-derived rootstocks are clones of the female parent, whose traits are known and selected by breeders, and they have predictable effects on fruit quality and yield and predictable resistance or tolerance to diseases and pests.

Polyembryony can be observed by germinating citrus seeds. If more than one seedling develops from one seed (fig. 17.4), one of the embryos (usually the weakest one) is of sexual origin, and the others are nucellar in origin. Reproduction primarily by nucellar embryony is an important trait of clonal citrus rootstocks in use today such as *Poncirus trifoliata*. Its seed are about 90% nucellar. The highly nucellar polyembryony of citrus rootstocks allows propagators in the citrus industry to rely on seedling clonal rootstock production. Reliably consistent rootstocks from seeds allows for a more rapid production of saleable plants.

Seedlessness and Parthenocarpy

Navel oranges and Satsuma mandarins do not produce viable pollen or fertile eggs; they set fruit without flowers being pollinated or fertilized, and therefore the fruit are seedless. Such fruit are known as parthenocarpic fruit. Parthenocarpic fruit development can be stimulated (increased) by pollination by another cultivar. No fertilization occurs, so fruit are seedless. Stimulated parthenocarpy generally increases fruit set, yield, and fruit size. For example, Hamlin orange pollen stimulates parthenocarpic navel orange fruit development, increasing yield and fruit size.

Alternate Bearing

Scientists have studied the problem of alternate bearing (the tendency for some citrus, such as Valencia oranges and some mandarins, to bear a heavy crop one year and a sparse crop the next), but they have not been successful to date in overcoming this problem. It is known that setting the heavy ”on” crop of fruit inhibits the growth of the summer and fall vegetative shoot flushes, reducing the number of nodes (sites) that can bear inflorescences the next spring, resulting in a low-intensity bloom and an “off” crop the following year (Verreynne and Lovatt 2009). For late-maturing cultivars, the presence of the on crop through spring bloom inhibits bud break, further reducing the intensity of the

bloom. You can balance the yields by removing some of the fruit when they are still tiny and green (before the summer vegetative shoot flush) during the heavy-bearing year and by harvesting a significant portion of the crop as soon as it matures.

Fruit Drop

An overwhelming number of citrus flowers drop during bloom, and considerable numbers of citrus fruit drop from trees throughout their development. Fruit drop is a natural phenomenon, a self-regulating thinning that protects citrus trees from bearing too many fruit. Usually, less than 5% of citrus blossoms produce mature fruit. Young, immature, and very small citrus fruit (less than 1 in in diameter) may drop from trees during bloom and in May and June. This is the first and most intense period of fruit drop, known as early drop. It is followed by June drop, which occurs during the period of rapid fruit growth from the end of June to just before the color break (September). During this period, progressively fewer fruit drop. A high percentage of fruit that persist through June drop remain on the tree until harvest. Preharvest fruit drop is the abscission of mature fruit prior to harvest. The number of preharvest fruit that drop increases with length of time past the normal maturity date of the cultivar. Fruit drop during these periods can be exacerbated by nitrogen deficiency, excessive nitrogen fertilization, sudden high temperatures, lack of water, heavy pruning, infestations of thrips or mites, or the occurrence of Santa Ana wind conditions in southern California. Keeping trees in good health minimizes fruit drop to expected levels.

Fruit Color and Regreening of Fruit

Fruit coloration in citrus (a change from green to orange or yellow) is associated with a loss of chlorophyll (green pigment) and an increase in carotenoids (yellow, orange, and red pigments) that occurs naturally as fruits mature. However, loss of green color and an increase in orange or yellow color in the fruit rind may not be correlated with fruit edibility. For example, in the fall, when temperatures are decreasing, chlorophyll loss occurs naturally in the fruit rind and carotenoids increase, but the color change, which is related to temperature, is not a good indicator of eating quality. Despite the mature-looking color of the fruit rind, additional days of low temperature may be required to increase sugar content or to decrease acidity in the juice vesicles before eating quality becomes acceptable.

Rinds of ripe Valencia oranges that remain on the tree during hot weather may revert from orange to green (regreening), but the fruit flavor does not change. The chromoplasts in the rind, which contain orange and yellow carotenoid pigments, can revert to chloroplasts, which contain the green pigment chlorophyll. In addition to high heat, high nitrogen fertilization may also contribute to regreening.

Sports

Sports are genetic mutations that affect only part of the tree, perhaps a branch or two. Typically, these mutations are not desirable, but if they are favorable, citrus breeders may choose to develop them into a new cultivar. The cultivars of the eating oranges Skaggs Bonanza and Robertson navel, among others, began as sports of the Washington navel. Washington navel was likely a sport of Bahia navel, from Brazil. Sports have foliage and fruit that are different from the rest of the tree. Pink Lemonade, which has pink flesh and variegated foliage, began as a sport of Eureka lemon. Development of sports is common in navel orange and grapefruit cultivars.

Fruit Quality and Production of Inferior Fruit

As a home gardener, your taste buds will be the judge of fruit quality. Commercially, oranges are graded according to size, sugar-acid ratio, weight, absence of blemishes, color, juice content, and other fruit

qualities. Each citrus-producing state has its own grading system. Many citrus types yield bland fruit for the first few years of production, but quality improves as trees mature. Off-bloom fruit of sweet orange, grapefruit, and tangelo (fruit that develop from flowers that bloom in the off-season) are often inferior. Disease, rainfall, or a dry spell followed by irrigation can trigger irregular or off-bloom. The inferior fruit that result tend to be thick skinned and puffy.

Citrus Cultivars

Where you live (which climate zone of the state) affects the citrus cultivars that perform best in your home garden or landscape, the harvest dates of fruits, and the pests and diseases that are common. Table 17.1, although not exhaustive, describes many cultivars of major and minor citrus crops grown by home gardeners. Additional information about citrus cultivars with pictures can be found online at the UC Riverside Citrus Variety Collection website, citruscultivar.ucr.edu/, and in other sources in the bibliography at the end of this chapter. Home gardeners may grow nearly all the citrus types listed in table 17.1 if cultivars are selected prudently for adaptation to the climate in a particular region. If cultivars are selected that mature at different times, fresh fruit can be harvested almost year-round. Selecting early-maturing cultivars in freeze-prone areas can facilitate harvesting before the danger of frost. In California commercial citrus production, navel oranges predominate in the San Joaquin Valley, Valencia (juice) oranges in the coastal and inland regions, lemons in the coastal regions, and grapefruit in the desert.

The primary sweet oranges consumed in California and worldwide are navels for eating as fresh fruit and Valencias for juice. Navel orange cultivars include the Washington navel and cultivars that began as sports of Washington, such as Robertson and Skaggs Bonanza. Some pomologists divide the sweet orange category listed in table 17.1 into two subcategories, navel oranges and common oranges, a catchall group of navel-less sweet orange cultivars that are juiced (Valencia) or eaten fresh and juiced (Trovita, Shamouti).

Climate Zones for Growing Citrus

The harvesting (maturation) dates given in table 17.1 are approximate and broad; they are based on dividing the state into five citrus-growing regions: Southern California Coast, Inland Southern California, California Desert Valleys, Central Valleys (San Joaquin and Sacramento Valleys), and Northern California Coastal Valleys. The most important factor that determines when fruit are mature and are ready for harvest is total heat. Maturation periods may vary from year to year and are influenced by microclimates. Citrus fruit grown in the desert are usually the first to mature, followed by citrus in the inland valleys. Citrus grown in coastal areas matures last. Fruit grown in the coastal zones can hang on the tree longer after maturity without deteriorating. Important attributes of the five zones are described below.

Southern California Coast. This region extends from San Diego to San Luis Obispo and includes Santa Barbara, Ventura, western portions of Los Angeles County and Orange County, and San Diego. The entire region is influenced by the Pacific Ocean, and the marine air produces a mild climate. Summers are moderate in temperature, and coastal fog is common. Winter temperatures are not usually a threat to citrus. Because many areas are frost-free, tender cultivars (limes and citrons) can be grown. Hot, dry winds known as Santa Anas can be damaging. This zone (especially Ventura County) is the most important commercial lemon production area in the United States; Eureka lemon bears here almost year-round. Valencia and Washington navel

oranges do well in the more inland areas of the region that have protection from wind. Compared with other citrus-growing regions in the state, fruit grown in this region mature last.

Inland Southern California. This region includes Riverside, San Bernardino, Pasadena, Glendale, Burbank, the San Fernando Valley, Ojai Valley, and Santa Paula. This region is hotter and drier in summer and colder in winter than the Southern California Coast and is more subject to hot, dry desert air. Santa Ana winds can damage fruit. In the past, this region was one of the state's most important commercial citrus areas. Today, sizable acreage remains, but urbanization has encroached significantly. Home gardeners in this area can grow almost any citrus cultivar. Summer heat needed to sweeten fruits is plentiful, and if the site is chosen prudently, trees and fruit can be protected from damaging winter cold.

California Desert Valleys. This region includes Palm Springs, Indio, and El Centro and the Coachella and Imperial Valleys. Summers are hot, long, and harsh. Daytime and nighttime temperatures fluctuate widely, and humidity is low year-round. Citrus cultivars that have high heat requirements, such as grapefruit and Valencia oranges, thrive in this region, yielding sweet, high-quality fruit. Lemons (Eureka and Lisbon), mandarins (Fairchild), tangor (Royal), and tangelos are also grown in the desert valleys. Citrus grown here matures early. Sunburned fruit, especially on the south side of the tree, can be a problem. Wind and extreme heat may adversely affect some citrus; some cultivars are not recommended for this region, such as Washington navels and Satsuma mandarins (see table 17.1). In the winter, frost protection may be needed. Citrus grown in the desert generally has less juice and a tougher rind than the same cultivars grown in milder climates.

Central Valley. This region includes the San Joaquin and Sacramento Valleys of central California and extends from Bakersfield to Redding. The San Joaquin Valley (Bakersfield, Visalia, and Fresno) has hot, dry, sunny summers and cold, wet winters. Winter temperatures are influenced by elevation and land slope. The tule fog in this region favors citrus because it acts as a thermal blanket. Today, the San Joaquin Valley is the most important citrus-producing area in the state. The Sacramento Valley includes the cities of Sacramento, Marysville, Oroville, Paradise, and Chico and surrounding areas. Summers are warm, and winters are cold and often dominated by tule fog. The slope and exposure of the planting site influence the cultivars that perform well. Early, hardy citrus cultivars, such as Washington navels and Satsuma mandarins, do best, but others can do well with protection.

Northern California Coastal Valleys. This region contains several climates influenced by the Pacific Ocean: the San Francisco Bay Area, Santa Cruz, San Jose, Monterey, Santa Rosa, Vacaville, Cloverdale, Napa, and Crescent City. In the summer, the weather can be cool, windy, and foggy near the coast but warm in inland areas, although usually not as warm as the Sacramento Valley. Cultivars with lower heat requirements do best near the coast. Although frosts are infrequent in the winters near San Francisco and in the thermal belts of many valleys in this region, low-lying inland areas can have temperatures below freezing. Site selection and winter protection are important factors in many locations in this region.

Cold Hardiness of Citrus Cultivars

Citrus types have different tolerances to cold temperatures. The following cold hardiness comparisons refer to the trees, not the fruit. Citron and lime trees are the most tender and cannot tolerate freezing weather; sweet orange and grapefruit cultivars are intermediate; and Satsuma mandarins and kumquats are the most

Table 17.1.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Sweet Oranges *(Citrus sinensis)* The most important citrus crop worldwide, with a taste different from sour and blood oranges. Believed to be natives of China, sweet oranges were first introduced into California by missionaries in 1769. The Washington navel was first planted in the state in 1873 in Riverside. Sweet oranges have had an important role in the development of California and continue to be a major player in the state's agricultural economy. Some references divide the sweet oranges into navels and common oranges.						
Cara Cara	A navel orange with deep pink juice vesicles that originated in 1976 as a sport on a Washington navel orange tree located at Hacienda Cara Cara in Venezuela. It does well in California. Most tree and fruit characteristics are similar to Washington navel, but the edible portion of the fruit is deep pink, similar to the dark red of some grapefruit varieties. The harvest period is similar to that of the Washington navel.	Jan–May	Jan–Apr	NR	Nov–Apr	Dec–May
Lane Late	Late navel. Matures 4–6 weeks after Washington navel. Adapted to warm inland and coastal valleys.	Feb–Jul	Feb–Jun	NR	Jan–May	NR
Robertson Navel	Fruit smaller and matures 2–3 weeks earlier than Washington navel. Fruit borne in clusters near outside of tree. Grown on dwarf rootstock in home gardens. Dwarf trees are highly productive. More heat resistant than Washington navel. Slow growing but bears at young age. Seedless, large fruit.	Jan–May	Nov–Apr	Nov–Jan	Nov–Apr	Dec–Apr
Shamouti	Midseason, nearly seedless eating orange developed in Israel. Has generated interest in some parts of California. Dense foliage, large leaves, and large fruit with excellent flavor. Grown on dwarf rootstock in home gardens. Highly productive. Popular in Europe and Israel. Also known as Jaffa.	NR	Jan–Apr	Dec–Mar	Jan–Apr	NR
Skaggs Bonanza	Bud sport of Washington navel. Matures about 2 weeks earlier than Washington. Trees bear fruit at earlier age than Washington. Can be picked earlier than Washington navel—a good choice where frost is a concern, but fruit do not hold on the tree as long. Heavy bearer. Performs well on coast.	Jan–May	Nov–Apr	Nov–Jan	Nov–Apr	Dec–Apr
Temple	See Temple cultivar of Tangor.					
Trovita	Uncommonly grown, navel-less seedling selection of Washington navel. A seedless, midseason eating and juice orange. Fruits well in desert conditions (unlike the navel), in moderate climates, and near the coast. Prized in San Francisco Bay Area because it develops excellent flavor without requiring high temperatures. Smaller fruit than Washington but juicier. Matures later than Washington. Bears heavily in alternate years. Developed at UC but known as one of the Arizona Sweets, a group of nonnavel oranges favored in Arizona because they tend to mature before hard frosts. Hamlin, Marrs, and Pineapple are other Arizona Sweets.	Feb–Jun	Feb–Apr	Jan–Feb	Feb–Apr	Feb–Jun
Valencia	Often called juice oranges. Thin-skinned, smaller fruit than navels, with highly juicy pulp. Few seed. Matures later than Washington navel: midwinter (hottest areas) to summer (coolest areas). Fruit store well on tree, improving in flavor, but may regreen in summer. Vigorous, productive tree available as dwarf or standard. Some newer cultivars are sold as "improved" Valencias, which mature earlier, set fruit inside the canopy (more protected), and boast bigger fruit. Three sold under separate names are Delta, Midknight, and Rhode Red. Valencia is still the most important orange cultivar worldwide.	Apr–Oct	Mar–Aug	Feb–May	Feb–Aug	Apr–Oct

Sources: UC Riverside Citrus Variety Collection; Ferguson and Grafton-Caldwell 2014.

Note: *Harvest periods are broad and general for a particular climate zone. Harvest periods (maturation dates) may vary slightly from year to year and can be influenced by microclimates. The harvest periods listed should not be interpreted as absolutely precise. These harvest periods are tailored to the home gardener who can wait for fruit to fully mature before harvesting. In a given climate zone, home gardeners typically harvest later in the season than commercial growers.

NR = not recommended.

Table 17.1. cont.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Washington Navel (Parent Navel Orange)	Large, seedless fruit eaten fresh, typically not juiced commercially. For the home gardener, the navel is excellent for fresh-squeezed juice if consumed immediately. Storage results in the accumulation of a compound in the juice that results in a bitter taste. Navels are suited to cooler production areas. Matures early; fruit can usually be picked before damaging cold weather begins. Easy to peel and separate. Primary commercial navel cultivar and the original one from which other navels have been developed. Does not do well in desert climates. Fruit splitting in Jan, Feb, and Sep is a common problem. Fruit stores on tree 3–4 months. Standard tree is 20–25 ft. On dwarf rootstock, it is about 8 ft.	Jan–May	Jan–Apr	NR	Nov–Apr	Dec–May
Blood Oranges *(Citrus sinensis)* Important commercially in Mediterranean but not in the United States. Many cultivars popular worldwide. Red blush on rind may not indicate internal flesh color, which is deepest in hot, interior regions. A gourmet's citrus, having rich orange flavor with raspberry overtones.						
Moro	Fruit is deep red, almost seedless. Juice is almost burgundy. Vigorous, spreading, productive, medium-sized tree. Fruit borne in clusters near outside of tree, making it an attractive ornamental. Early-maturing Italian cultivar. Best rind color (red blush) occurs in hot, interior regions of state. The only blood orange with good color and flavor in coastal northern California. Very thorny.	Feb–May	Jan–Mar	Nov–Feb	Dec–Apr	Feb–Apr
Sanguinelli	Rosy-skinned fruit makes plant decorative. The most popular blood orange in Spain. Sweet-tart juice vesicles are streaked with burgundy. Adapted best to warm inland and desert valleys.	Apr–Jun	Mar–May	Feb–Apr	Mar–May	Apr–Jun
Tarocco	Italian cultivar. Less productive than Moro, but deep red fruit are larger, good flavor. Little rind blush. Few seed. Fruit do not hold well on tree. Juice is almost burgundy. Vigorous, spreading, medium-sized tree. For reliable color and sweetest flavor, adapted best to inland valleys. Color is not reliable in other locations. New selections with higher internal color are available named Bream and Thermal.	Mar–May	Jan–Mar	NR	Jan–Mar	Mar–May
Sour Oranges *(Citrus aurantium)* Sour oranges include many unique citrus cultivars used as landscape ornamentals, for making the liqueurs Curacao and Cointreau, as an ingredient in perfumes, and for manufacturing marmalade, candies, and rind oils. Fruit is very sour, almost bitter, in flavor, and too strong for many people. Flowers are very aromatic, and the aroma of leaves and rind oils is distinctive. Sour oranges have darker green foliage and more flattened fruit, which tend to be deeper orange in color than other orange types. Smaller sour orange trees are useful as hedges. The larger Seville is a common street tree in southern California and Arizona. Fruit can be held on the tree for 9–10 months.						
Bouquet de Fleurs	Prized ornamental with deep orange fruit set among unique, round, deep green, densely clustered foliage. Has the most aromatic of all citrus flowers; set in massive clusters; used by perfume makers. A good hedge or container plant for the patio. Tree is small, 8–10 ft, spreading. The dwarf cultivar can be used as an ornamental shrub wherever pittosporum would be effective in the landscape.	Jan–Mar	Dec–Jan	Nov–Dec	Dec–Jan	Feb–Mar
Chinotto	Sometimes called myrtle-leaf orange. Small, symmetrical tree (7 ft) with dense, compact growth habit. Fruit set in clusters. Prized in Italy for making candy, and fruit are also used for jellies and preserves. Fruit hold on the tree almost year-round. Attractive ornamental tree in the yard or as a container plant. Can also be trimmed as a hedge.	Jan–Mar	Dec–Feb	Nov–Dec	Dec–Feb	Jan–Mar

Table 17.1. cont.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period* Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Seville	Upright, thorny, large tree (20–30 ft). Its seedy fruit make excellent marmalade. Excellent as an ornamental for the home landscape. Traditionally used in courtyards.	Jan–Mar	Dec–Feb	Nov–Dec	Dec–Feb	Jan–Mar
LEMONS *(Citrus limon)* Lemons are a sour-fruited citrus. Acid content is highest just prior to fruit maturity. Pick when fully mature. Left on the tree, lemons become pithy and lose flavor. Lemons are more frost-sensitive than other citrus types but do not need high heat to mature since they are not sweet. Most commercial lemons are grown in the coastal regions of California, particularly in Ventura County. Lisbon and Eureka are the true supermarket lemons. Unlike many other citrus types, some lemon cultivars should be pruned.						
Eureka	Depending on location, Eureka may be everbearing or harvested 3 to 4 times per year. Tree is medium sized (20 ft), less thorny than other lemons. Fruit and flowers are in highly visible clusters. Attractive as container tree. Frost-sensitive. Flowers and new growth tinged with purple. Productive, high-quality fruit, but relatively short-lived tree. A major commercial cultivar. Needs periodic pruning. Good for espalier.	Feb–Sep	Feb–Jul	Sep–Jan	Feb–Jul	year-round
Improved Meyer	Fruit is round, thin skinned, and almost orange when ripe. Hybrid between a lemon and a sweet orange or mandarin. Very juicy fruit with less acid than other lemons. Some seed. Imported from China; the most popular citrus in the home garden. Usually grown as a rooted cutting. Often bears fruit the first year. Ornamental, hardy, spreading, small tree (< 15 ft). Ideal for containers. Also makes an excellent hedge. Few thorns. Needs no pruning. More cold-hardy than true lemons.	year-round	Nov–Mar	Nov–Mar	Nov–Mar	year-round
Lisbon	Depending on location, may be everbearing. Vigorous, tall (30 ft), thorny tree. Most productive, cold-hardy, and heat tolerant of true lemons. Flowers tinged with purple. Highly acid, juicy fruit. Pick when mature. A major commercial cultivar. Fruit is similar to Eureka, but tree is thornier and more frost tolerant. The best lemons for the desert; fruit is borne inside the canopy. Needs pruning once per year to keep within bounds and shapely.	Jan–Aug	Dec–Jul	Sep–Jan	Dec–Jul	year-round
Variegated Pink	Sport of Eureka with green and white leaves and green stripes on immature fruit. Light pink flesh. Grows to about 8 ft. Frost-sensitive. Good as container plant. Also known as Pink Lemonade.	Feb–Sep	Feb–Jul	Sep–Jan	Feb–Jul	year-round
Grapefruit *(Citrus paradisi)* Grapefruit trees are among the largest citrus types. Standard trees grow to about 30 ft. On dwarf rootstock they are about 8 ft tall. Grapefruit are borne in grapelike clusters toward the outside of the tree, which, with its fruit and large, glossy, green leaves, is very ornamental. Grapefruit requires high heat to develop the best sweet-tart flavor. Excellent grapefruit grow in Texas and Florida, where humidity is above 60%, summers are hot with warm nights, and winters are sunny with cool nights. Good grapefruit can be grown in California, but maturation time will vary from 6 months to more than a year, depending on climate, because of the total heat required. Allow fruit to hang on the tree to sweeten up. The grapefruit × pummelo hybrids developed at UC Riverside (Melogold and Oroblanco) do not require as much heat to mature. Nonetheless, all grapefruit should be planted in the warmest location (a southern exposure or in front of a wall that will reflect the heat of the sun). Grapefruit have pale yellow or rosy flesh.						
Duncan	Oldest grapefruit cultivar in Florida. Cultivar from which all others in the United States developed. Better flavor than modern seedless types but very seedy, white flesh. Great for juice. Adapted to the California deserts, but not recommended in cool coastal areas.	NR	NR	Nov–May	NR	NR

Table 17.1. cont.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Marsh, Redblush	Marsh is the standard, commercial white-fleshed grapefruit. Seedless. Originated in Florida as a seedling of Duncan. A parent of Redblush, which is rosy fleshed if it receives enough heat. Redblush is also known as Ruby and Ruby Red. Both Marsh and Redblush are almost identical trees. Desert conditions are best for peak quality due to the high heat requirement. In other climates, fruit mature later and are less sweet.	May–Nov	Feb–Aug	Jan–May	Jan–Jun	Apr–Nov
Oroblanco, Melogold	Both are grapefruit × pummelo hybrids adapted to warm inland valleys and coastal regions. Both were developed at UC Riverside. Sweet and low in acid. Seedless, white flesh. Needs less heat than true grapefruit. Oroblanco is sweeter than Melogold and is more frost tolerant.	Jan–Apr	Nov–Jan	Nov–Jan	Nov–Jan	Jan–Apr
Other cultivars	Star-Ruby is well suited to western Riverside, San Bernardino, and San Diego Counties but is not recommended for desert or coastal climates. Frost sensitive, bears erratically, but has the reddest flesh color. Rio-Red may be more dependable than Star-Ruby and is also recommended for desert valleys.	NR	Feb–Aug	NR	Jan–Jun	NR
Limes *(Citrus aurantifolia)* Like lemons, limes are an acid-fruited citrus. They are one of the least cold-hardy citrus types and must be grown in frost-protected locations. Limes are divided into large- and small-fruited types. Left on the tree, limes turn yellow. Maturity is a function of juiciness, not rind color. The Rangpur "lime" is actually a sour-acid mandarin and is included in that category in this table.						
Bearss	Also known as the Persian or Tahitian lime in Florida and Texas. A large-fruited, seedless lime sold in grocery stores. A Tahitian cultivar was introduced into the state at Porterville. Like the lemon and unlike the Mexican lime, Bearss does not require much heat to mature. Attractive, ornamental, medium-sized, vigorous tree. Fruit are pale yellow when ripe but can be used when green. The most valuable lime for western gardeners because there is a better chance of success with it than with the Mexican cultivar.	Aug–May	Aug–Mar	Aug–Jan	Aug–Mar	Aug–Mar
Indonesian	See Kafir lime.					
Kafir lime, caffre lime, or kieffer lime *(C. hystrix)*	Not a true lime. Small shrubby tree with pungent leaves popular in Thai, Indonesian, and Cambodian cooking. Juice, leaves, and rind are used and not the fruit of this species. The fruit is small with irregularly bumpy rind. When the fruit reaches full maturity in late winter to early spring, the rind turns yellow. Fruit falls from the tree when fully mature. Juice sometimes used to make a shampoo that repels insects. Suitable for growing in containers.	Sep–Dec	Sep–Dec	Sep–Dec	Sep–Dec	Sep–Dec
Mexican	The bartender's lime. In Florida, known as the Key lime. A small-fruited lime more adapted to tropical climates in Florida and Mexico than California. High heat demand and almost no tolerance for frost. Planting a dwarf in a sheltered location, in a container, or in front of a south-facing wall may help. Highly aromatic. Twiggy, thorny, small tree usually grown on its own roots. Also known as the West Indian lime.	Jul–Dec	Jul–Dec	Jul–Oct	Jul–Nov	Aug–Dec
Persian	See Bearss.					
Rangpur	See Sour-Acid Mandarins, Rangpur.					

Table 17.1. cont.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Sour-Acid Mandarins Most mandarins are sweet and eaten fresh, but a few mandarins (Rangpur and Calamondin) are distinctly acidic. Both can be used as ornamentals. Dwarfs of Rangpur and rooted cuttings of Calamondin make excellent house plants, fruiting reliably indoors. Both Rangpur and Calamondin are ever-bearing in mild climates and are cold-hardy.						
Calamondin	Mandarin × kumquat hybrid, popular in Asia, particularly the Philippines. Its easy-to-peel rind is sweet and edible (due to its kumquat parentage), and the fruit is acidic and tangy. It looks like a small orange. In the United States, Calamondins are used primarily as ornamentals. The variegated form of Calamondin is especially used as an ornamental.	flowers and fruits year-round	flowers and fruits year-round	flowers and fruits year-round	flowers and fruits year-round	flowers and fruits year-round
Rangpur	Native to India. It is used as a rootstock for other citrus cultivars. Its acidic juice can be substituted for lime juice, but it is not a lime, even though it is sometimes referred to as the Rangpur lime. Its reddish orange fruit look and peel like mandarins and can hang on the tree all year.	Sep–Jun	Sep–Jun	Sep–Jun	Sep–Jun	Sep–Jun
Mandarins *(Citrus reticulata; C. unshiu; C. deliciosa; C. nobilis)* The mandarins are the largest, most varied group of edible citrus. They are described as zipper-skinned because they are easy to peel and separate into segments. In the United States, mandarins are often called tangerines. Fruit are smaller and often sweeter than sweet oranges. Many cultivars mature in winter and do not have a high heat requirement to yield a good crop. Other cultivars yield a sweeter, juicier crop if heat is high during the latter part of the maturation period. Harvest fruit when mature; early-season cultivars do not store well on the tree, but mid- and late-season cultivars store better. The rind will get puffy and the flesh will lose its flavor if they are left on the tree too long. Many are alternate bearers. Removing some of the crop during the heavy-bearing year prior to summer vegetative shoot growth can even out the harvests a little. There is probably a mandarin cultivar for every climate in the citrus belt. Foliage is more cold tolerant than the fruit. Grow early-maturing cultivars in frost-prone areas. Most mandarin trees are small to medium size (10–20 ft) with few thorns.						
Clementine *(C. reticulata)*	Major commercial cultivars in California. Excellent flavor, early-season fruit. Introduced from North Africa and Spain. Fruit holds on tree, making it an excellent ornamental, but fruit quality is reduced. Yields best fruit in the interior but produces well in cooler climates. There are many selections, such as Algerian, Caffin, Fina Sodea, Nules. Those that require a pollinizer for good production have seedy fruit. Dancy and Kinnow mandarins, Orlando tangelo, and Valencia orange are commonly used as pollinators. Clementine has produced many hybrids, such as Page, Fairchild, Ambersweet, Lee, Nova, Robinson.	Jan–Apr	Nov–Jan	Nov–Dec	Nov–Jan	Jan–Apr
Dancy	Seedy. Better suited to Florida than California. Needs high heat to yield sweet fruit. Introduced into Florida from Morocco. Smaller than most mandarins. Heavy bearer in alternate years. Sunburn can be a problem in the desert.	Feb–Apr	Jan–Mar	Dec–Jan	Jan–Mar	Feb–Apr
Royal	See Temple cultivar of Tangor.					
Satsuma *(C. unshiu)*	One of the most cold-hardy citrus and the earliest bearer. Can be grown in areas normally too cold for citrus. Matures before dangerous frosts occur, and the foliage survives temperatures to about 22°–18°F (–5° to –8°C). Popular in the Sacramento Valley and Sierra foothills as well as other areas in the state. Easy-to-peel seedless fruit with mild, sweet flavor. Dobashi Beni, Kuno Wase, Okitsu Wase, and Owari are Satsuma selections that thrive in cooler regions. None are suited to low deserts. Dobashi Beni and Okitsu Wase both have mature fruit at the end of Oct. Owari is a month later.	Dec–Apr	Nov–Jan	NR	Nov–Jan	Dec–Apr

Table 17.1. cont.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Mandarin Hybrids						
Delite	See W. Murcott.					
Encore	Developed at UC Riverside. Late-maturing cultivar. Sweet, juicy, seedy, easy-to-peel, medium-size, speckled fruit. Medium-sized tree. Alternate bearer. Hybrid of King × Mediterranean mandarins *(C. nobilis × C. deliciosa).*	May–Jul	Apr–Jul	Mar–Jun	Apr–Jul	May–Aug
Fairchild	Early-maturing, seedy, Clementine mandarin × Orlando tangelo hybrid adapted to the desert and inland valleys but not to the coasts. Rich-flavored, medium-sized, juicy fruit hold fairly well on tree. Tree has few thorns.	NR	Nov–Jan	Nov–Dec	Nov–Jan	NR
Gold Nugget	Seedless, late maturing, with a rich sweet flavor. Fruit store exceptionally well, up to 6 months. Rind is paler and coarser than other mandarins. Parentage is complex; a hybrid of Wilking (Willowleaf × King) × Kincy (King × Dancy) mandarins.	Mar–Jun	Feb–May	Dec–Jan	Mar–May	unknown
Honey	Midseason cultivar. Very sweet, juicy, seedy, fruit. Hybrid of King × Mediterranean mandarins *(C. nobilis × C. deliciosa).* Superior flavor. Very easy to peel. Small-size fruit. Alternate bearer. Medium to large tree. Do not confuse with the Honey tangerine sold in grocery stores, which is Florida's Murcott tangor.	Feb–Apr	Jan–Mar	Dec–Feb	Jan–Apr	Feb–Apr
Kinnow	Developed at UC Riverside. Very sweet, juicy, seedy, medium-size, easy-to-peel fruit. Aromatic. Large, willow-like, ornamental tree. Alternate bearer. Hybrid of Mediterranean × King mandarins *(C. deliciosa × C. nobilis).*	Apr–May	Feb–Apr	Dec-Feb	Feb–Apr	Apr–May
W. Murcott (W. Murcott Afourer)	A tangor of unknown parentage introduced to California from Morocco in 1985. The tree is moderate in size and vigor. Fruit are usually flattened, with a thin, smooth orange rind. The flesh is orange and juicy, with a rich sweet flavor. Fruit are low seeded in the absence of cross-pollination but seedy when cross-pollinated. As with most mandarins, W. Murcott is susceptible to alternate bearing.	Mar–Jun	Feb–Mar	NR	Feb–Mar	Mar–May
Page	Result of a cross between a Clementine mandarin and a Minneola tangelo. Small to medium-sized, usually seedless fruit whose rich flavor is considered by some to be the finest among the mandarins. Easy to peel. Attractive tree with few thorns.	Feb–May	Dec–Feb	NR	Dec–Feb	Feb–May
Pixie	Late-maturing cultivar adapted to coastal regions and inland valleys. Seedless, mild, juicy, sweet fruit. Alternate bearer. Easy to peel. Small- to medium-size fruit with bumpy rind. Fruit holds exceptionally late on the tree; in certain mild locations, the fruit is known to hold well into summer. Developed and released by UC Riverside.	Apr–Jun	Mar–Jun	NR	Apr–Jul	Apr–Jul
Seedless Kishu	Small tree makes good choice for container specimen. Fruit is small, no more than 2 in diameter. Sets reliable crops of fruit that are bright orange, seedless, mild flavored, sweet, juicy, and very easy to peel. Early in maturity, and the fruit holds well on the tree but peel puffs and becomes less attractive with time.	Nov–Jan	Nov–Jan	Nov–Jan	Nov–Jan	Nov–Jan

Table 17.1. (cont.)

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Shasta Gold (TDE 2)	Recent release from UC Riverside's citrus breeding program. Hybrid with Temple tangor and Dancy and Encore mandarins in its parentage. Vigorous, somewhat thorny trees that tend to alternate bear. Fruit large and seedless with rich, sweet flavor and dark orange rind. Flesh is bright orange and juicy. Fruit holds well on tree.	Feb–Apr	Feb–Mar	Feb–Mar	Feb–Mar	Feb–Mar
Tahoe Gold (TDE 3)	Recent release from UC Riverside's citrus breeding program with tree and fruit characteristics very similar to Shasta Gold. Fruit does not hold well on tree.	Jan–Apr	Jan–Feb	Jan–Feb	Jan–Feb	Jan–Feb
Tango	A new selection of W. Murcott Afourer developed by the UC Riverside citrus breeding program. It remains low seeded to seedless even when cross-pollinated with other citrus. Tree and other fruit characteristics are the same as W. Murcott Afourer.	Mar–Jun	Feb–Mar	NR	Feb–Mar	Mar–May
Yosemite Gold (TDE 4)	Recent release from UC Riverside's citrus breeding program with tree and fruit characteristics very similar to Shasta Gold, but trees less thorny. Fruit holds well on tree.	Jan–Apr	Jan–Mar	Jan–Mar	Jan–Mar	Jan–Mar
Tangelo *(Citrus tangelo)* Tangelos are hybrids between a mandarin and a grapefruit. The *"tang"* portion of the name is a shortened version of *"tangerine,"* a popular name for mandarins. The *"elo"* comes from pummelo, a term the citrus industry was promoting instead of grapefruit. Tangelos are adapted best to hot climates. Their yields are higher and seedier if a mandarin or tangor is nearby for cross-pollination. At the grocery store, tangelos are sometimes incorrectly called oranges, mandarins, or tangerines.						
Minneola	The most important commercial tangelo in California and the best for home gardens. Bright orange-red fruit with conspicuous neck. Minneola is a cross between a Dancy mandarin and a Duncan grapefruit. The fruit has good color and is borne toward the outside of the tree, making it a good ornamental. A cross-pollinator (Dancy, Clementine, or Temple tangor) increases production. Seedy, juicy fruit that peel well. Rich, tart, unique flavor. Best in hot climates.	Feb–Apr	Jan–Mar	Jan–Feb	Jan–Mar	Mar–May
Orlando	Same parentage as Minneola. Fruit mature a month earlier than Minneola and are more orange-like in shape and color. Very juicy, seedy, mildly sweet. Tastes more like a mandarin than Minneola. Slightly hardier than Minneola. Adapted well to hot desert regions. Not recommended for coastal areas. Tree is similar, except for cupped leaves. For best results, requires a cross-pollinator. Peels poorly.	NR	Dec–Feb	Nov–Dec	Dec–Feb	NR
Tangor *(Citrus nobilis)* Tangors are hybrids between a mandarin and a sweet orange. In the grocery store, they are often mislabeled as oranges. They are adapted best to Florida's climate but can be grown in the California desert or hot inland valleys, depending on the cultivar.						
Murcott	So sweet it is marketed under the name Honey tangerine. Its fruit are yellowish orange and seedy. Can be grown in hot inland valleys, but is not recommended for the California coasts or desert. Matures late. Easy to peel. Holds well on tree.	NR	Feb–Mar	NR	Feb–Mar	NR
Ortanique	Tree is medium sized, dense, and round in form. Fruit medium sized, orange, and exceptionally juicy. When cross-pollinated, the fruit is seedy. Flavor is rich and sweet. Usually late in maturity and fruit holds very well on the tree.	Jan–Apr	Jan–May	Jan–May	Jan–May	Jan–May

Table 17.1. (cont.)

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Royal	See Temple.					
Temple, or Royal	Needs high heat and is adapted only to the California desert. It is not recommended in the coastal valleys, the inland valleys, or the Central Valley. Tart, seedy fruit mature in winter. Trees are more sensitive to cold than mandarins and oranges.	NR	NR	Jan–Feb	NR	NR
Kumquat (*Fortunella spp.*) Kumquats are oval- to round-shaped citrus fruit that look like very small oranges, except that their rinds are edible, spongy, and sweet. The pulp is tangy and moderately acidic. Whole, unpeeled fruit are edible—rind and all—making kumquats unique citrus fruits. Dwarf trees grow to about 3–6 ft tall. Standard trees are about twice that size and have multiple uses in the landscape. Trees are excellent for ornamental use. The tree is symmetrically shaped with dark green leaves, richly perfumed white blossoms, and showy orange-colored fruit. Dwarf cultivars make excellent hedges or container plants for patios. Kumquats require high heat to bloom and set fruit. One of the most cold-hardy citrus. Scientists have hybridized them with other citrus types (limes, mandarins), seeking cold-tolerant hybrids. Kumquats are named after the botanist Robert Fortune *(Fortunella)*, rather than grouped with the fruits in the *Citrus* genus. Kumquats grow actively only in high heat, but nighttime chill is essential for good color and flavor development. Kumquats bloom later than other citrus types and stop growing earlier; thus, they are adapted to the coolest limits of the citrus belt.						
Indio manderinquat, Hybrid kumquat	A hybrid between Nagami kumquat and Dancy mandarin. Fruit are small, pear shaped, with reddish orange rind, and tend to be seedy. Flavor is sweet, and peel is tart.	Dec–Apr	Dec–Apr	Dec–Apr	Dec–Apr	Dec–Apr
Meiwa *(Fortunella crassifolia)*	A popular cultivar in China and Japan. The best cultivar for eating fresh fruit and for cooler climates. Sweet flesh, spicy, thick rind. In Asia, it is also used for making candies and preserves. Excellent ornamental. Few to no thorns. Does well in warm, sunny locations. Fruit can store on the tree for up to a year. Sweeter, juicier, and less seedy than Nagami. Very cold-hardy.	Jan–Apr	Dec–Mar	Dec–Mar	Dec–Mar	Jan–Apr
Nagami *(Fortunella margarita)*	The most popular commercial cultivar in the United States. Slightly seedy. Good container plant. Easy to espalier; thornless. Fruit can store on tree for up to a year. Sweet rind, tart flesh. Fruit shape is more oblong than Meiwa.	Jan–Apr	Dec–Mar	Dec–Jan	Dec–Mar	Jan–Apr
Nordmann	Seedless selection of Nagami. Tree small to medium in size with a fine, dense texture. Semidormant in winter, relatively cold-hardy. Flowers in summer, fruit matures in winter and holds well on the tree. Fruit up to 2 in long, hang in ornamental clusters. The fruit are seedless, and the rind is sweet while the light orange flesh is acidic.	Jan–Apr	Dec–Mar	Dec–Jan	Dec–Mar	Jan–Apr
Limequat Limequats are hybrids of a Mexican lime, which is very cold-sensitive, and a kumquat, which is very cold-hardy. The USDA, which sponsored the breeding program, was attempting to capitalize on the cold hardiness of kumquats and extend that trait to other citrus types. Limequats are an excellent lime substitute and are much more cold-hardy than the lime parent. Fruit have flavor and aroma that approximate a lime with an edible, sweet rind from the kumquat parentage. Limequats require less heat than their lime parents. Fruit are yellow when ripe. Not a commercial success but worthy of consideration by home gardeners. On dwarf rootstock, they are 3–6 ft tall. Highly suitable for ornamental use and easy to espalier, they bear abundant fruit. Adapted to all citrus-growing zones in California.						
Tavares, Eustis		Dec–Jul	Nov–Jul	Nov–Jul	Nov–Jul	Dec–Jul
Orangequat The USDA sponsored the plant breeding program that led to the development of the orangequat, which is a cross of a Meiwa kumquat and a Satsuma mandarin.						

Table 17.1. cont.

SELECTED CITRUS CULTIVARS FOR PLANTING IN THE HOME GARDEN AND LANDSCAPE

Scion cultivar	Comments	Harvest period*				
		Southern California Coast	Inland Southern California	California Desert Valleys	Central Valley	Northern California Coastal Valleys
Nippon	Fruit are deep orange in color, a little larger than a kumquat, and can be eaten rind and all. The spongy rind is sweet and the pulp is juicy and slightly acidic. The overall flavor is sweeter than a kumquat. Fruit require less heat to mature than kumquats. They have few seed and are adapted to all citrus regions in California. Compact, handsome plant is excellent for espalier or containers. Fruit stores on the tree for months before losing flavor. Use fresh, for marmalade or candied fruit. Especially prolific during the Christmas season. Very cold-hardy.	Dec–Sep	Dec–Jul	Nov–Mar	Nov–Aug	Dec–Sep
Pummelo *(Citrus grandis)* Pummelos are the largest citrus fruit. They have firm flesh but thicker rinds and lower juice content than grapefruit. Pummelos are not eaten in the same manner as grapefruit; they are peeled, segmented, and the juice vesicles are shelled out of their membranes. The shelled segments are eaten with or without sugar. Pummelos vary in flavor from very sour to high sugar/low acid to nonacid. The color of juice vesicles ranges from buff to pink to deep red. Some are seedy, and others are seedless. Trees vary in size, shape, and growth habit. Pummelos need less heat to mature than grapefruit. Fruit can hold on the tree for several months.						
Chandler	Developed at the UC Riverside Experiment Station. Good sugar-acid pummelo flavor. Yellow rind with pink flesh. A hybrid between two pummelos (Siamese Pink × Siamese Sweet). Many seeds unless grown in isolation from other citrus. Open growth habit suitable for espalier.	Apr–Jun	Dec–Apr	Dec–Feb	Dec–Apr	Apr–Jun
Hirado Buntan	Pink fleshed, adapted to inland valleys and desert.	NR	Dec–Apr	Dec–Feb	Dec–Apr	NR
Reinking	Developed at the USDA Citrus and Date Experiment Station in Indio. Not as sweet as Chandler. Rind is yellow with pale yellow flesh. Many seeds unless grown in isolation from other citrus.	Apr–Jun	Dec–Apr	Dec–Feb	Dec–Apr	Apr–Jun
Tahitian	White fleshed, adapted to inland valleys and desert.	NR	Dec–Apr	Dec–Feb	Dec–Apr	NR
CItron *(Citrus medica)* Like the lemon and lime, the citron is a sour fruit, but unlike the lemon and lime, the flesh of the citron is lacking in juice. The fruit are large and oblong, and the yellow rind is very thick. Since the rind oils are very aromatic, historically it was used as a room deodorizer and moth repellent. Today, its most typical uses are in religious ceremonies and in fruitcakes. The rind of the citron is candied and used to make fruitcake "fruit."						
Buddha's Hand	Sometimes referred to as a fingered citron, since it is divided into finger-like sections at one end. Others have referred to the fact that it looks like a citrus octopus or a bunch of gnarled bananas. The fruit consist entirely of rind, no pulp. In Buddhism, this fruit is a symbol of happiness. Grown in the United States as a novelty, it is used as a perfumant and as an ornamental in Asia. Very cold-sensitive.	everbearing	everbearing	everbearing	everbearing	everbearing
Etrog	The fruit used by people of the Jewish faith to celebrate the Feast of Tabernacles. Shaped like an oversized lemon but has ridges along the rind. Very dry, acidic pulp with little practical use other than for candying. Very cold-sensitive.	everbearing	everbearing	everbearing	everbearing	everbearing

Sources: UC Riverside Citrus Variety Collection; Brenzel 2012; Ferguson and Grafton-Cardwell 2014.

Note: *Harvest periods are broad and general for a particular climate zone. Harvest periods (maturation dates) may vary slightly from year to year and can be influenced by microclimates. The harvest periods listed should not be interpreted as absolutely precise. These harvest periods are tailored to the home gardener who can wait for fruit to fully mature before harvesting. In a given climate zone, home gardeners typically harvest later in the season than commercial growers. NR = not recommended.

cold-hardy. In general, the most tender to most hardy species are

citron
Mexican lime
lemon
grapefruit = pummelo
tangelo = tangor = sweet orange
sour orange
Satsuma mandarin = Meyer lemon
kumquat

Mexican lime trees are damaged at temperatures below freezing (32°F), whereas kumquats are cold-hardy to 18° to 20°F. Larger fruits, such as grapefruit, that are protected by leafy branches can endure temperatures of 24°F. The duration of the cold temperatures, the fruit's position on the tree, the tree's location and age, and the cold tolerance of the rootstock are important factors that affect cold hardiness. Foliage can protect fruit from the cold. Avoid planting citrus in low spots in the garden, where cold air accumulates. Young, succulent growth and blossoms are the most susceptible to cold; thus, late-spring frosts can be the most damaging.

Home gardeners have the alternative of growing citrus in containers and sheltering the plants in the winter by bringing them indoors if the outdoor winter temperatures exceed the plants' cold hardiness range. Success in growing citrus depends on your ability to avoid subjecting the plants to temperatures beyond their cold hardiness range.

Heat Requirement of Citrus Cultivars

Citrus cultivars that contain higher levels of acid and are not expected to be sweet, such as lemons and limes, do not require high heat. They perform well in cooler locations along the coast, which permit several harvests year-round. Lemons can also be grown in hotter regions, but the heat limits the harvest dates. In the desert, lemons mature mainly in late fall and winter. Unlike lemons, grapefruit have a high heat requirement and are of the highest quality when grown in desert locations. When homeowners grow grapefruit near the coast, they should leave them on the tree to increase gradually in sweetness.

In areas of the state that are too cool for high-quality grapefruit, home gardeners can choose the grapefruit × pummelo hybrids Melogold and Oroblanco, which require less heat to sweeten (see table 17.1). Grapefruit grown in pots can be brought indoors to avoid exposure to freezing temperatures.

Rootstock Cultivars

Unless you do your own bud grafting at a CDFA-certified nursery, you will need to purchase a citrus tree at a nursery. Nursery-grown trees are composed of one of the scion cultivars listed in table 17.1 grafted onto a rootstock cultivar selected by the nursery. Labeling laws in California do not require the nursery to list the rootstock cultivar used; knowledgeable nursery personnel may be able to inform you of the rootstock. Because the rootstock cultivar provides the lower portion of the trunk and the roots of the tree, it influences fruit productivity, size, and quality, overall tree vigor, resistance to soilborne fungal diseases, nematodes, viruses, viroids, environmental stresses, and cold hardiness (table 17.2). Thus, it is useful to know which rootstock cultivar you have purchased. Because rootstocks have a major influence on tree performance and fruit quality (table 17.3) and are important to the California citrus industry, UC conducts long-term research projects on rootstock cultivars. This brief discussion of citrus rootstocks has been adapted from *Integrated Pest Management for Citrus*, 3rd edition (Dreistadt 2012), and *Citrus Production Manual* (Ferguson and Grafton-Cardwell 2014). See those resources for more detailed information.

The UCR Citrus Clonal Protection Program eliminates the possibility of known virus and viroid bud-transmissible infections in the scion, such as tristeza, exocortis, and psorosis. Budwood from the

Table 17.2.

PEST AND DISEASE SUSCEPTIBILITY AND STRESS RESPONSES OF SELECTED ROOTSTOCKS USED IN CALIFORNIA CITRUS

Condition*	Trifoliate Orange	Troyer Citrange	Carrizo Citrange	Macrophylla	C-35 Citrange	Swingle	Rough Lemon	Sour Orange	Sweet Orange
tristeza virus	T	T	T	S	T	T	T	S	T
Phytophthora root rot	T	MT	MT	T	T	T	S	T	S
Phytophthora gummosis†	T	T	T	T	T	T	S	T	S
Armillaria root rot	—	S	S	S	S	—	S	S	—
exocortis (viroid)	S	T	T**	T	—	T	CD	T	T
citrus nematode *(Tylenchulus semipenetrans)*	T	T	T	S	T	T	S	S	S
cold hardiness	G	G	G	P	A	G	P	G	A
poor drainage	A	U	U	CD	U	U	U	A	U
salinity	P	U	U	A	P	P	A	G	—
calcareous soils	P	U	U	A	U	U	A	G	P
scion used	oranges mandarins	oranges mandarins Lisbon lemon grapefruit	oranges mandarins Lisbon lemon grapefruit	lemons (only)	oranges mandarins Lisbon lemon grapefruit	oranges mandarins Lisbon lemon grapefruit	lemons grapefruit oranges kumquat	oranges grapefruit	oranges mandarins grapefruit

Sources: Dreistadt 2012, p. 23; Ferguson and Grafton-Cardwell 2014.

Notes:

*A = acceptable; CD = conflicting data; G = good; MT = moderately tolerant; P = poor; S = susceptible; T = tolerant; U = unsatisfactory; — = no data.

**Exocortis-infected trees grafted on Carrizo Citrange rootstock may show a general decline and poor performance even in the absence of the typical rootstock bark scaling symptom.

†Phytophthora gummosis affects the trunk of the tree.

CCPP that tests negative for these and other citrus diseases is used to propagate trees sold in nurseries. However, to keep your trees disease-free and avoid any future problems, it is best to select a rootstock resistant to these infections in the scion. Proper preplant assessment and preparation of the soil should manage potential soilborne pests and diseases that can attack citrus. However, if parasitic nematodes and *Phytophthora nicotianae* (formerly *P. parasitica*) or *P. citrophthora* oomycetes (fungus-like microorganisms) are endemic in the area where you live, you should choose a resistant or tolerant rootstock (see table 17.2).

Four dominant rootstock cultivars

Troyer and Carrizo Citranges (Sweet Orange × Trifoliate Orange hybrids). In the citrus industry today, Troyer and Carrizo Citranges, which are hybrids of *Citrus* and *Poncirus* spp., are the most common rootstocks used with scions of sweet oranges, mandarins, grapefruit, and some lemons. In climates outside the citrus belt, citranges are grown as landscape or fruit trees. They are hardy to 5° to 10°F. Until the late 1940s, Sour Orange, Rough Lemon, Sweet Orange, and Cleopatra Mandarin were the major California rootstocks, but today, Troyer and Carrizo Citranges have largely replaced these older rootstocks because the Citranges are more tolerant to some serious diseases in California, particularly tristeza. Approximately 65% of the rootstocks produced between 1950 and 1970 were Troyer. It was the standard by which all other California rootstocks were judged. Recently, Carrizo and C-35 have also been widely planted. Both Carrizo and Troyer are prone to zinc and manganese deficiencies.

Trifoliate Orange *(Poncirus trifoliata)* **(Rubidoux and Pomeroy)**. As noted in table 17.2, both the Citranges and Trifoli-

ate Orange are tolerant to citrus tristeza virus, *Phytophthora* spp. that cause root rot, and *Phytophthora citrophthora*, which causes gummosis of the bark, but they are susceptible to Armillaria root rot. Trifoliate Orange is tolerant to citrus nematode but susceptible to exocortis.

Trifoliate Orange is cold-hardy to about –15°F, which is its distinct advantage. Because it is the most cold-hardy rootstock, it has been planted extensively in the San Joaquin and Sacramento Valleys. It is a common rootstock with scions of sweet oranges and mandarins. Outside or inside the citrus belt, trifoliate orange can be grown as an ornamental. It is a thorny, deciduous shrub or small tree that produces large, fragrant blossoms in spring, followed by leaves consisting of three leaflets. Its fruit are inedible but hang on the tree until the following winter, making it a decorative landscape plant. When trifoliate orange is the rootstock, the fruit quality is good; however, fruit rinds may crease and split. Trifoliate Orange rootstock is sensitive to exocortis, alkaline soil, and zinc deficiency. Trees on Trifoliate Orange develop a bench at the bud union because the rootstock is larger than the scion; this is normal.

Flying Dragon Trifoliate Orange. A natural dwarf that grows to about 6 feet tall, Flying Dragon has a dwarfing effect on fruiting cultivars grafted onto it, which typically grow to about half the standard size.

Macrophylla *(Citrus macrophylla)***.** Macrophylla (formerly known as Alemow) is the most popular rootstock for lemons grown along the coast. It is susceptible to tristeza, citrus nematode, and Armillaria root rot, but it is tolerant to Phytophthora root rot, Phytophthora gummosis, exocortis, and saline soil and water conditions.

Older rootstock cultivars not currently favored

Sour Orange *(Citrus aurantium)***.** Sour Orange is very susceptible to tristeza, which

Table 17.3.

EFFECTS OF ROOTSTOCKS ON HORTICULTURAL TRAITS

Trait	Trifoliate Orange	Troyer Citrange	Carrizo Citrange	Macrophylla	C-35 Citrange	Swingle	Rough Lemon	Sour Orange	Sweet Orange
tree vigor	low	medium	medium	high	low	medium	high	medium	medium
tree size	medium/ large*	medium/ large*	medium/ large*	medium	medium	medium	medium/ large*	medium/ large*	large
drought tolerance	low	medium	medium	—	—	medium	high	high	low
total soluble solids in fruit†	high	high	high	low	high	high‡	low	high	high
fruit acidity	high	high§	high	low	high	high‡	low	high	high
fruit juice %	high	high	high	low	high	high	low	high	high
fruit size	medium	medium	medium	large	medium	medium	large	medium	medium/ small
fruit yield	medium/ high	medium/ high	medium/ high	high	medium/ high	medium‡	medium/ high	medium/ high	medium/ high
fruit peel	smooth	medium#	medium#	coarse/thick	medium	medium#	coarse/ thick	smooth/ thin	—

Source: Adapted from Roose 2014.

Notes:

*Varies with scion and location.

†Abbreviated as TSS; a measure of the sugar content of citrus fruits.

‡In arid climates, produces better yields and higher quality of Redblush grapefruit and Orlando tangelo than most rootstocks, including Sour Orange.

§Can produce acid fruit in cool areas.

#Exacerbates creasing with a sweet orange scion.

can be fatal to citrus. Prior to the tristeza outbreak in the 1940s, Sour Orange was the rootstock of choice for sweet oranges in California. This was because of its resistance to Phytophthora gummosis, which had devastated the California citrus industry earlier in the 1900s. Today, 15 to 20% of California citrus acreage is planted on Sour Orange rootstock.

Rough Lemon *(Citrus jambhiri)***.** Rough Lemon is not cold-hardy and is susceptible to Phytophthora root rot, Phytophthora gummosis, and other citrus diseases, but it can be used as a rootstock for lemon and grapefruit in the desert regions of the state.

Rootstock cultivars recently released by UC

C-32 Citrange (Sweet Orange × Trifoliate Orange hybrid). C-32 Citrange, an unpatented UC release in the early 1990s, produces a large, vigorous tree with good yields of excellent-quality fruit. It is equal to Troyer Citrange in Phytophthora spp. and nematode tolerance. It appears to have the best potential as a San Joaquin Valley rootstock for navel and Valencia oranges.

C-35 Citrange (Sweet Orange × Trifoliate Orange hybrid). C-35 Citrange produces a smaller tree with all scion cultivars. Fruit quality is good and yields are good, except with navels. C-35 is very tolerant of nematodes and is generally more tolerant of Phytophthora than C-32 or Troyer. This rootstock was an unpatented UC release in the early 1990s. Since 1995, it has been used for many trees sold to home gardeners.

Swingle Citrumelo (Grapefruit × Trifoliate Orange hybrid). The major advantages of Swingle Citrumelo are its tolerances to Phytophthora gummosis, Phytophthora root rot, drought and cold, Citrus nematode, and tristeza. Exocortis usually causes no obvious symptoms, although some stunting has been reported. This rootstock produces high yields of good-quality fruit equal to that produced by scions on Troyer or Carrizo Citrange. Disadvantages include sensitivity to high water tables and calcareous soil, evidence of scion overgrowth in both oranges and grapefruit, and a tendency for the fruit to exhibit the rind disorder known as creasing.

Schaub Rough Lemon. Schaub Rough Lemon has not been tested extensively, but thus far it has better Phytophthora tolerance than Rough Lemon.

Volkameriana *(Citrus volkameriana).* The major advantage of Volkameriana is its cold tolerance, which is superior to that of Rough Lemon or Macrophylla. It also produces better-quality fruit than Rough Lemon or Macrophylla but is otherwise similar to Rough Lemon.

Rootstock incompatibilities with scions

True incompatibilities between a scion and a rootstock are rare. Most less-than-effective scion-rootstock combinations are eliminated in the research stage because of poor productivity, poor tree performance, and poor fruit quality and size. For example, Eureka lemon is incompatible with Trifoliate Orange and most Citranges. However, some incompatibilities, such as some bud union disorders, do not manifest until 10, 15, or 20 years after planting. One example is bud union crease, a fold formed at the bud union, which, with increasing overgrowth, compresses the conducting elements and girdles the tree. The one- to two-decade delay before this problem is evident confirms how essential the long-term UC research on citrus rootstocks and scions is to the California citrus industry, as well as the home gardener. The most susceptible combinations are Frost nucellar navel on Trifoliate Orange, followed by Satsuma mandarin on Troyer Citrange (bud union creasing occurs at 15–20 years), and certain scion lines on Sour Orange. Frost nucellar navel on Trifoliate rootstocks have shown decline at 10 to 20 years because of bud union disturbance. Similarly, navel oranges on Swingle rootstock show decline after about 20 years. Fukumoto navel on Carrizo Citrange, C-35, Volkameriana, or Trifoliate Orange

rootstocks produce many water sprouts and suckers at the bud union, typically starting in the second year after planting, suggesting a potential incompatibility. The survival rate of these scion-rootstock combinations is variable, but poorly growing trees should be replaced.

Future development of California citrus rootstocks

The pressure on the California citrus rootstock industry caused by the tristeza virus in the 1940s is now in the past. However, a new, very destructive bacterial (associated with *Candidatus* Liberibacter spp.) disease, huanglongbing (HLB), also known as citrus greening disease or yellow dragon disease, now poses a very serious threat to the citrus industry in California and worldwide. The disease is spread by psyllid insects and through grafting with infected budwood. The Asian citrus psyllid (ACP) *(Diaphorina citri)* vector is present in California and rapidly spreading throughout the state. Whereas huanglongbing has been detected in backyard trees near Los Angeles and eradicated, it has not yet been detected in commercial citrus orchards in California. For further details, refer to the section “Pests, Diseases, and Environmental Stresses,” below. Because of the increasing frequency of pest and disease threats to the California citrus industry, new rootstock cultivars must be developed continuously. Moreover, it is estimated that nearly 30% of the state’s citrus production, which consists of grapefruit, lemons, limes, tangelos, tangors, and mandarins, lacks the optimal rootstock, a problem that increases in magnitude as the commercial citrus industry continues to shift northward within the state. The citrus tristeza virus, *Phytophthora nicotianae*, *P. citrophthora*, and citrus nematode continue to be major problems among widely used rootstocks. Only Trifoliate Orange, C-35, and Swingle Citrumelo tolerate all four well. Also, a better rootstock for calcareous soil and saline conditions is badly needed.

A Consumer Guide to Identification of Citrus Rootstocks

Citrus trees are sold on many different rootstocks. The characteristics summarized in this chapter show that rootstocks can alter many aspects of tree behavior; thus, the consumer may wish to know what rootstock is used for a tree. There are two situations when rootstock identification may be important: when purchasing a tree at the nursery and when an older tree has problems that may relate to its rootstock.

Identifying the rootstock on a new purchase

When the tree is purchased, it may be labeled with the rootstock, but this is relatively rare. Sometimes rootstocks are labeled by painting colored rings onto the trunk, but different codes are used by different nurseries, so this is not very helpful to the buyer. Generally, the only clue to the rootstock is given by the expected tree size (dwarf, semidwarf, standard), as shown below:

Labeled size	Rootstocks used
dwarf	Flying Dragon, occasionally others; check for a bud union
semidwarf	Unknown, Trifoliate Orange, or no rootstock (scion is grown on its own roots)
standard	Carrizo, Troyer, Rough Lemon, Sweet Orange, Sour Orange

Trees on the dwarfing rootstock Flying Dragon (a cultivar of Trifoliate Orange) are the easiest to identify: even young trees have the characteristic bud union, with the scion being smaller than the rootstock. This bench will become quite pronounced by the time the trees are several years old. Trees on Trifoliate Orange also produce this trademark bench, but these trees will be larger than those on Flying Dragon by the time the bench develops. If the tree is not labeled and does not have this characteristic bud

union, it is rather difficult to determine the rootstock.

Identifying the rootstock on an older tree
For older trees that are already planted in the ground, an educated guess often can be made about the rootstock using the guidelines listed below:

Bud union/other characteristics	Possible rootstock
almost undetectable	Sweet Orange
smooth but detectable	Sour Orange
lumpy bulge; lemon scion	Macrophylla
slight bulge, many suckers from rootstock	Rough Lemon
moderate bench	Troyer, Carrizo, C-32, C-35
pronounced bench	Trifoliate, Swingle
severe bench; dwarf tree	Flying Dragon

When shoots arise from below the bud union, their leaf type can be helpful in identifying the rootstock. Sweet Orange, Sour Orange, Macrophylla, and Rough Lemon have unifoliate leaves, whereas the other rootstocks have trifoliate leaves.

Selecting, Budding, and Buying Citrus Trees

Purchase plants from a reputable California nursery or California mail-order supplier and be certain that the label identifies the scion precisely. Find out which rootstock has been used. Mail-order citrus is available bare-root or potted. Citrus at the nursery or garden center is available in containers of 5, 7, or 15 gallons and sometimes in 1- or 2-gallon pots. Be certain the scion cultivar is labeled and note whether the desired rootstock has been used. Rootstock selection is particularly important when seeking a dwarf tree. Young specimens that have not begun to bear usually transplant more easily and are less expensive than the larger trees.

Inspect the plant carefully before you buy. Choose a healthy-looking plant that has foliage with strong green, uniform color, no blemishes or nicks on the bark, a smooth bud union, fairly symmetrical branching, and no obvious pest damage (chewed leaves or signs of insects). Inspect the underside of leaves, the shoots, the bark, the soil surface, and the bud union. Make sure that the bud union is located far enough above the soil level to prevent disease problems at the bud union. A straight, strong trunk is preferred because it may not require staking. Plants that have roots protruding from the container have been in the container too long and should not be purchased.

Budding a Citrus Tree

To bud or graft a citrus tree, refer to the section on budding in chapter 5, "Plant Propagation." Note especially the T-budding technique, which is commonly used with citrus. You will need budwood (a twig of the scion cultivar with buds along its length) and a rootstock.

You may be able to purchase budwood from a nursery specializing in citrus or from the UCR Citrus Clonal Protection Program (CCPP), ccpp.ucr.edu, at the Department of Plant Pathology and Microbiology, UC Riverside. This pathogen-testing budwood program focuses on protecting citrus cultivars from bud-transmissible diseases and providing via therapy new cultivars for the state's commercial industry. Minimum orders of six buds (one stick) are required. Budwood is available monthly, and orders for budwood can be placed online (see the CCPP website). A list of available cultivars can be requested. Because the CCPP is a quarantine program operating under state and federal compliance, budwood can be sold throughout the state, but it is illegal for it to be moved from county to county or to move trees and propagating materials without permits from the local county agricultural commissioner or the California Department of Food and Agriculture. Quarantines are presently in place within

California to prevent the spread of the Asian citrus psyllid, a vector for huanglongbing. A quarantine to prevent the spread of tristeza is also in effect. Check with your local agricultural commissioner before transporting citrus trees between counties.

Before budding your tree, be certain that the scion-rootstock combination is compatible and that the rootstock is adapted to your area. Bud when the rootstock is actively growing and the bark is slipping (loose enough to peel back when you make the T cut; see the section "Care of Pruning Tools" in this chapter), which occurs in California from April through August. Bud far enough above the soil line to avoid disease problems. In commercial citrus propagation in California, buds are inserted at a height of about 12 to 18 inches. Note that because the citrus tree scion is genetically identical to its parent tissue, and the rootstock is genetically identical to its parent tissue, budding the scion to the rootstock is known as clonal propagation.

Multiple-Cultivar Citrus Trees

You might consider creating a multiple-cultivar citrus tree. Such trees are sometimes referred to as fruit cocktails and may be a useful alternative if space is limited. Because each cultivar grows at a different rate, the multiple-cultivar tree may not be as attractive or aesthetically balanced as the single-fruiting cultivar, but it may serve a useful purpose in your garden. You can bud additional cultivars onto an existing citrus tree in your yard or create your unique tree at the outset. Follow the basic T-budding instructions in chapter 5. Sweet orange, mandarin, tangelo, grapefruit, and kumquat can all be used interchangeably as budwood on several compatible rootstock cultivars. Eureka and Lisbon lemons do not work well in multiple-cultivar formats; they are best as single trees. If you are not interested in doing the budding yourself, multiple-cultivar citrus trees can be purchased.

Planting

To grow citrus successfully in your garden, select a site wisely, choose appropriate scions and rootstocks adapted to your area, and employ cultural management practices that yield high-quality, abundant fruit.

When to Plant

Although citrus can be planted any time of year, the best timetable depends on the climate in your area. Your goal in selecting when to plant is to give the tree's roots the longest possible time to become established before they are subjected to environmental stresses, such as freezing or extreme heat. In freeze-prone regions, early spring is usually best because it gives the tree many months of growth to become acclimated before cold weather and danger of frost occur. In areas that have very hot summers, such as the desert, fall planting is good because the tree will have time to get acclimated before scorching heat occurs. Fall planting is also a good option in frost-free regions along the coast.

Site Selection: Where to Plant

Citrus can be planted indoors or outdoors, in containers, or directly into the ground. Optimal soil pH is between 6.0 and 7.5, and soil depth must be at least $1\frac{1}{2}$ feet. Soil textures ranging from sandy to clay loams are best. A wind-free location that has full sun and heat, preferably a south-facing exposure, is ideal. Other locations are workable if you take advantage of their slope and exposure to radiant energy (the sun) and avoid cold air pockets. If you are planning to plant in a location where citrus or avocado trees have previously died, you should review the suitability of this location, including whether a fungicide treatment of the soil is needed to eradicate root rot fungi that could interfere with tree establishment.

A garden's microclimates

Every garden has microclimates, small areas in the garden that differ from the general climate, such as the cool shade under a large tree on a hot summer day or areas where increased light and heat are reflected from a wall. You can take advantage of these microclimates in selecting the site for growing citrus. The south-facing side of a house typically gets the most consistent sun all day. It is the warmest location, especially in the winter. Citrus grown on the south side, unless it is shaded by tall trees, will receive the most sun and warmth. Heat-demanding cultivars, such as grapefruit, will probably do best in the hottest microclimate in your garden. Night temperatures against a south-facing wall that releases heat absorbed during the day may be several degrees higher than in an open area.

The west side is warm and sunny in the afternoon and is the second-warmest area of the yard. The east side is usually the first to warm up in the morning but is less warm than the west side. The north side tends to have more shade and is the coldest microclimate. North-facing slopes are cooler and moister than south-facing slopes, which are usually warmer and drier.

Planting in raised beds and espaliering against a south wall (see the section "Maximizing the Planting Area," below) can increase the heat available to citrus. Screens can reflect heat onto trees and deflect damaging winds. Because cold air moves toward the lowest altitude and can cause frost damage to citrus if temperatures are low enough, provide cold air drainage in your home garden and plant on the slope rather than at its base, where cold air accumulates. A fence at the base of a slope can trap cold air. Wind can increase heat loss, resulting in additional fruit damage. Judicious use of windscreens or buffers can direct cold or desiccating winds away from trees, while at the same time reflecting more heat onto trees.

Sizing up the site

Allow enough space for the tree to grow to its mature size. Over the years, a standard-sized citrus tree may grow up to 20 to 30 feet tall and be equally wide. Its roots will extend well beyond the canopy. As discussed above in the section on roots, citrus roots may extend twice as far as the drip line, that imaginary circle below the canopy edge. Space should be available for a root system of this size, and water and fertilizer applications should include the area beyond the drip line. Do not plant citrus trees near plants with aggressive root systems that will compete for water and nutrients.

Dwarf trees need much less space than standard-sized trees, but the caveats about allowing enough space to overcome competition for nutrients and water still apply because their roots extend beyond the canopy edge. If space is very limited, consider espaliering citrus trees, training them to grow flat against a wall or supporting structure as discussed later in this chapter (see fig. 17.29).

Planting a citrus tree in a lawn is not recommended. If the lawn is the only space available, then remove the turf in a 3- to 5-foot circle, depending on the mature tree size, to reduce competition from turf roots for water and nutrients. Removing the turf also eliminates the risk of a lawnmower or a weed trimmer nicking the tree's trunk, which would allow a portal for entry by pathogens. Citrus trees should not be irrigated on the same schedule as the turf because this increases the risk of root rot.

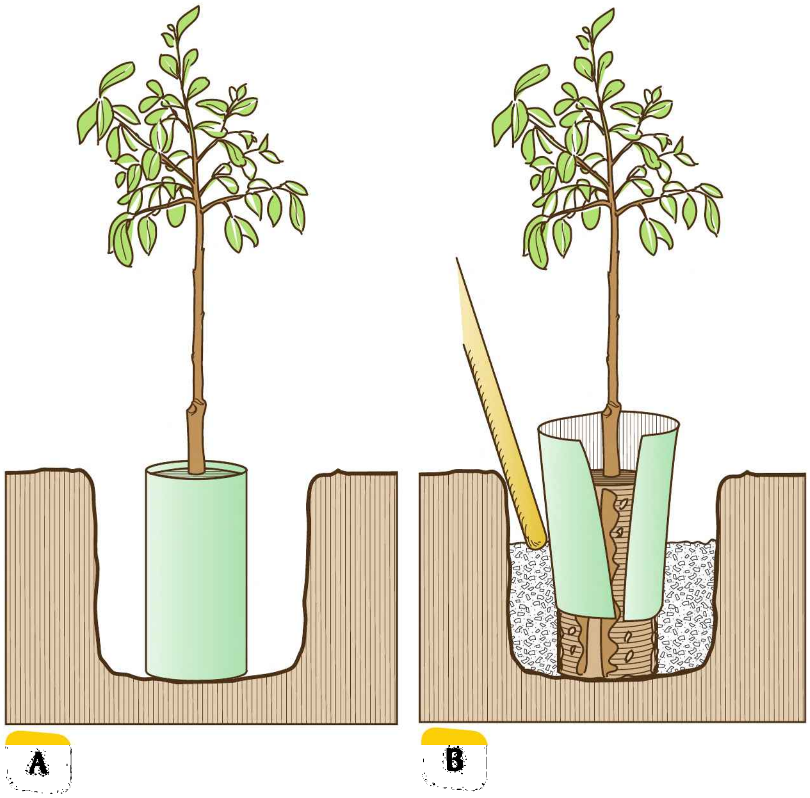
How to Plant a Citrus Tree

A fully leaved subtropical evergreen tree, such as a citrus, must be treated differently from a typical bare-root, temperate deciduous fruit tree. The following discussion of planting a citrus tree is adapted from *Planting and Management of Citrus and Avocado Trees* (Brokaw Nursery n.d.).

Citrus is planted in the spring or fall. Special allowance must be made for cit-

Figure 17.5

Planting a citrus tree. (A) Hole should be twice the width of root ball and the depth adjusted so that the upper surface of the tree ball is about 1 inch above the surrounding ground. (B) Slice container and remove from root ball, then backfill with native soil and gently tamp.



rus' high transpiration rate. Citrus trees have tender, succulent roots, so their earthen balls may not be as physically stable as those of other plants. Never lift or carry them by grasping the trunk of the scion or the stake; always grasp a citrus tree below the bud union. Be sure the tree is lowered and correctly set in the planting hole before you slit the container.

- Dig a hole much wider than the ball of your tree. In general, the hole should be about as deep as the root ball and about twice its diameter (fig. 17.5). For a tree in a 3.5-gallon sleeve, an ideal hole is about 16 to 18 inches wide and about 20 inches deep. Save the soil for backfill. If the soil is not too light (sand) or heavy (clay), you do not need to add soil amendments to the hole. UC farm advisors recommend that you do not use soil amendments at planting time unless extreme conditions exist, such as adobe clay soil.
- Adjust the depth of the hole so that the upper surface of the tree ball is about 1 inch above the surrounding ground when the tree is lowered into it. Avoid placing moist soil against the trunk above the original soil line, as this increases the risk of disease.
- Lower the tree into the hole, then slice the container vertically on one side. Next, backfill with 6 to 8 inches of loose soil (which should fill the hole about one-third full) to stabilize the tree before removing the slit container. Do not move the root ball after the container is slit.
- Take the plastic container out of the hole and discard it (the sleeve, which is recyclable but not degradable). This procedure leaves the roots exposed on the surface of the ball. Note that many of the roots are concentrated at the outside of the vertical surface.
- Gently tamp the loose soil around the ball immediately. Promptly fill the rest of the hole with loose soil, gently tamping as you fill. Fill it to the top, but leave the upper surface of the original ball exposed.
- The soil used to backfill the hole should be free of large clods because they can cause large air spaces that prevent fine roots from contacting the soil and are detrimental to water movement through the backfill.
- The upper surface of the ball is left exposed so that you may add water directly to the ball, even after the tree is planted. It is best to leave the upper surface exposed because the soil in the ball may have been specially formulated with nutrients and designed so that the upper surface of the ball will readily absorb water. If you cover this surface with anything, do not use soil; use sand, loose sawdust, coarse gravel, or anything water will pass through very rapidly.
- Because citrus trees can have many shallow roots, the soil around them should not be disturbed by cultivation. Control weeds with frequent mowing, hand-weeding, or mulches. Herbicides should be used only as a last resort and must be applied carefully so as not to

harm the tree. Use only herbicides labeled for use on citrus and follow label directions.

Water the tree immediately after planting and keep the root ball moist, but not soggy or flooded, until roots grow out into the surrounding soil. The surface roots concentrated at the outside of the ball will die if they dry out.

Irrigation

Timely irrigation is essential for proper citrus tree growth, development, and fruiting. Overdrying and overwatering harm citrus health. Do not allow the root system to completely dry out, since this may cause stunting, reduced yield, and tree death. Drought stress can be a problem; however, a much more common problem is excess water. More citrus trees die from excess water, which can be due to overirrigation or poor soil drainage, than die from drought. Because citrus trees are evergreen, they need water year-round. Demand for water is high when trees are growing actively, which usually occurs from late winter or early spring through the summer. Demand is highest when evapotranspiration (ET) is highest, usually in the summer months.

The most critical period for irrigation is from the year's initial growth flush until the young fruit are at least 1 inch in diameter. Trees cannot perform well if denied a quality water supply. Irrigation water should be relatively free of salt and toxic ions. Irrigation water should not come into contact with the tree trunk (from soil line to above the bud union) because such water may encourage soilborne diseases such as Phytophthora root rot and Phytophthora gummosis, which can kill the tree. The trunk and the bud union should stay dry.

Always water newly planted trees immediately after planting, because the surface roots concentrated at the outside of the ball will not be able to function properly unless they are kept moist. The tree's active, working leaves must be supplied with water at all times to ensure proper functioning. Three common irrigation methods for citrus trees are basin flooding, sprinkler irrigation, and drip irrigation.

Basin-Flooding Young Trees

Build a basin with a 3-foot diameter around the newly planted tree (fig. 17.6). During the first year, fill the basin with water until the water penetrates just below the bottom of the original root ball. Eventually, the water will need to penetrate 2 to 3 feet. If the soil or root ball have settled, adjust the bottom of the basin. Once the basin has stabilized, the bottom can be covered with wood chips or some other mulching medium that does not become soaked. Basin irrigation can be used for up to a full year; during the wet season, if water has any tendency to stand, the basin should be broken down. Avoid allowing water to pond around the trunk.

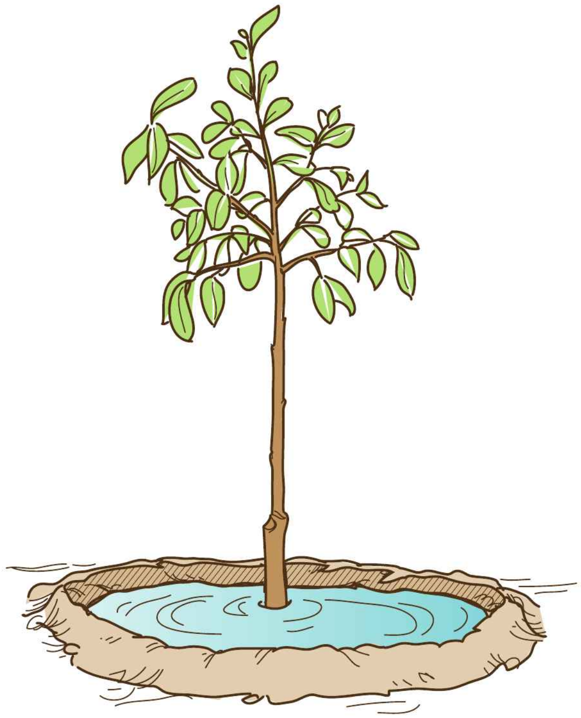
Sprinkler and Microsprinkler Irrigation

If sprinkler irrigation is used for citrus trees, enough water must be applied during an irrigation to wet most of the root system. Supplemental irrigation using a hose may be needed to keep the root ball of newly planted trees thoroughly moist. Construction of a basin, as in flood irrigation, is useful with sprinkler irrigation during the first year after planting because it aids in holding irrigation water over the root ball and facilitates the hand-watering that may be needed. Another option is to form a basin and use a bubbler emitter instead of a microsprinkler emitter so that water fills the basin. After a year, the bubbler emitter can be replaced with a microsprinkler.

If the citrus tree is located in a lawn, which is not recommended, avoid watering it with sprinkler irrigation. Lawn sprinklers are effective for watering turf, which has roots that may extend several

Figure 17.6

Basin irrigation.
Source: After Citrus 1996, p. 38



inches deep, but they are not particularly effective in providing moisture to citrus tree roots, which are located to a depth of about 2 feet. In general, the top roots of the tree are overwatered when it is located in the lawn.

Drip Irrigation

Drip irrigation systems dispense water slowly, in gallons per hour, rather than in the gallons per minute typical of lawn sprinklers. If you use drip irrigation for newly planted trees, use one emitter per tree and be sure that the emitter is fastened to the exposed root ball with a U-shaped piece of wire or hook. Attaching the emitter prevents the dripper from creeping away from the root ball as the hose expands and contracts. Check your emitters frequently to be sure that each tree is getting watered. Clogged emitters are a common problem. In the second year, it is best to use two emitters, one on each side of the trunk about 8 inches away from it. As the tree grows, more emitters can be added. A mature tree about 8 to 10 years old may have 6 to 8 emitters. In orchards, two parallel lines of emitters are sometimes used. The majority of citrus roots are in the top 2 feet of soil, with the heaviest concentration in the top foot. Most feeder roots are usually in the top 6 to 12 inches and are concentrated around the emitters.

Irrigation Frequency

Irrigation frequency is influenced by climate; thus, the irrigation schedule must be changed as seasons change through the year. Some of the water applied is absorbed by the roots; some of the water taken up by the roots is moved to the leaves and is lost from leaf surfaces by transpiration; and some evaporates from the soil surface. Evapotranspiration losses increase during hot, dry, windy conditions, and consequently the demand for water increases. Soil type also influences irrigation frequency because of its effects on water-holding capacity. Disregard the dryness of the top inch of soil, which dries out rather quickly even though the underlying soil may still be moist. As a rule of thumb, water when the top few inches of soil are dry but the rest of the root zone still feels slightly moist. Water young trees more frequently than established trees. Depending on the climate, trees may need to be watered every few days from June through September. Always pay attention to the soil moisture and make adjustments as temperatures increase. A quick method of determining water stress in citrus is to look at the trees in the morning (not later in the day). If you see the backs of the leaves (the leaves are cupped and a paler green color is showing) in the morning, the trees are water stressed. If you see mostly flat, dark green leaves (the tops of leaves are showing), the water status of the tree is good. Hot, windy weather will necessitate more frequent irrigation. Cool, overcast days place little demand on the water supply, and irrigation is required less frequently.

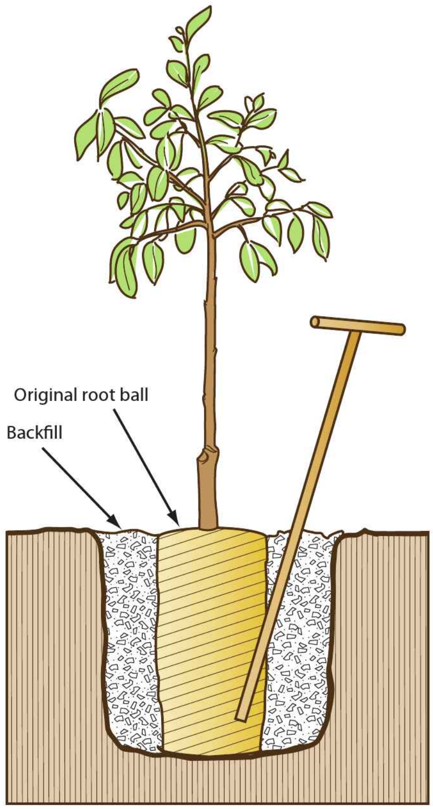


Figure 17.7

Use a soil core probe to detect soil moisture content. *Source:* After Brokaw n.d., p. 1.

Irrigation Amount

In general, for a newly planted tree, 2 to 5 gallons of water per irrigation per tree is sufficient to keep the root ball moist. Once the tree has begun to establish a root system, keep the soil damp, but do not allow the soil to remain soggy (saturated). Saturated soil lacks air in pore spaces, creating an anaerobic environment that favors disease. Alternate wetting and drying allows oxygen to enter the soil, which is necessary for root growth.

Table 4.1 in chapter 4 lists average daily evapotranspiration (ET) rates for a 4-inch-high cool-season turfgrass when unlimited water is available, which is the reference planting that scientists refer to in comparing water use among plant species. Mature citrus trees use about 0.7 times the figures in the table. Younger trees use less, and newly planted trees use the least, about 0.02 times the reference ET rates.

Water deeply, since citrus root systems are usually several inches to 2 feet deep. A mature tree with an extensive root system requires more water to wet the root zone than does a young tree with a smaller root mass, but the young tree's roots dry out faster. On newly planted trees, you can determine soil moisture content with a soil probe slanted toward the side of the root ball so that it penetrates the ball about 12 inches below the soil surface; apply water according to the needs of the tree (fig. 17.7).

Drought Stress and Dried-Out Fruit

When a citrus tree is water stressed, it will extract water from developing and mature fruit, causing them to dry out. Developing and mature fruit serve as a source of water for the tree when the tree is experiencing drought. Keep trees adequately watered while fruit are developing to prevent this problem.

Freeze and Sunburn Protection

Citrus trees and fruits are at risk from freezing. Temperatures in the middle 20°F range result in fruit losses; low 20°F and high teens are thresholds for leaf and twig damage; and lower temperatures extensively kill large branches and limbs. The best growing sites take advantage of slope and exposure to obtain energy from the sun and avoid pockets of cold air. If you live in a frost-prone area, a number of short-term protection measures and long-term precautions can increase your overall preparedness.

Short-Term and Long-Term Frost Protection

Young citrus trees, in particular the foliage, are very vulnerable to prolonged frost conditions, but immediate precautions can protect the trunk and foliage and often save a tree when a frost is predicted.

Short-term response to prediction of frost

Protecting the trunk: Thermal wraps. Wrap the trunk of a new tree with an insulating material, such as heavy corru-

gated cardboard, several layers of newspapers, cornstalks, date palm fronds, or special thermal wraps. Wrap to a point above the bud union (fig. 17.8). Even if the exposed parts of your tree are killed, it is likely that you will have a budded tree when winter is over. At the onset of spring, you will be able to unwrap the damaged tree and select a shoot or shoots above the bud union to renew the tree. Do not remove dead tree parts until new shoots are growing well.

Protecting the trunk: Sawdust-filled collar. A more effective insulation alternative to preserve the bud union is a collar 5 to 6 inches in diameter filled with sawdust to about 6 to 12 inches above the union. It is almost impossible to freeze tissue within this mass of sawdust.

Protecting the foliage. Use canopies, not plastic. A suspended canvas and wood canopy above the tree will help to protect foliage. Wrapping straw around and through foliage can also provide insulation. Some home growers have used lighted electric bulbs inside tents in extreme conditions. Trees do not survive well in darkness; they must be allowed sunlight during the day. Do not use polyethylene or other nonbreathing plastic. A completely enclosed covering of these materials is often worse than nothing, especially when it touches the tree. Foliage touching the cover will be damaged by the cold.

Irrigation practices when a frost is predicted. Water the soil a day or two before the freeze and again after it hits. Moist soil holds more heat than dry soil. The irrigation water releases heat as it cools and freezes. Do not sprinkle the tree because ice forming on branches can break them.

Figure 17.8

Wrapping the trunk of citrus in an insulating material to protect it from freezing temperatures. *Source:* After Citrus 1996, p. 16.

Long-term frost protection

Cultivar selection: Cold hardiness and early ripening. Choose cold-tolerant scion cultivars and rootstocks. Review the information about cold hardiness of different citrus types in tables 17.1 and 17.2 before making your selection. Choose early-ripening cultivars, such as Satsuma mandarins and Washington navels, which allow you to harvest before the threat of frost.

Site selection. Take advantage of your garden's warmest microclimate, such as a south-facing slope or near a wall that radiates heat. Bare soil holds more heat than soil with a cover crop; therefore, remove weeds and other plants from beneath the canopy.

Fertilization practices. To prevent stimulating new growth during the coldest time of year, start fertilizing after the last spring frost and stop in late summer.

Irrigation practices. Because stressed plants are more susceptible to freeze damage, keep citrus trees well irrigated in frost-prone areas. Frost-injured fruit will dry out on the tree.

Pruning practices. Do not prune in fall or winter because pruning can stimulate tender new growth.

Container planting. If freezes are frequent and severe, plant citrus in containers that can be sheltered during the harshest times of year.

Sunburn Protection

Protect the trunk and large limbs from sunburn. Lemon trees are particularly sensitive to sunburn. Wrap the trunk of a newly planted tree with newspapers or tree wraps and tie loosely. The trunks and exposed branches of older trees can be painted with a mixture of one-half water and one-half interior white latex paint to protect them from sunburn.

Fertilization

Successful fruit production requires an adequate supply of nutrients essential to trees. Deficiencies reduce yields and adversely affect fruit size, color, sweetness, and peel texture. Professional growers use leaf tissue analysis information as guidelines for fertilizing their trees for optimal yield production. The primary nutrient that home gardeners need to supply is nitrogen; phosphorus and potassium do not need replenishment as often. In certain areas of the state and in some soil, magnesium, iron, zinc, manganese, copper, boron, and molybdenum may be deficient. In other soil, boron may be in excess.

Nitrogen Fertilization and the Nonbearing Years

Young citrus trees in the nonbearing years (the first 2–3 years) have different nitrogen requirements than mature, fully bearing trees. In the nonbearing years, citrus trees should be fertilized adequately to encourage maximum early growth.

Home gardeners may sprinkle a tablespoon of nitrogen-bearing fertilizer (e.g., ammonium nitrate or urea) every 3 or 4 weeks over the root area of nonbearing trees and water it in thoroughly. Alternatively, home gardeners can spread 2 tablespoons of nitrogen fertilizer three to four times per year under young citrus trees before irrigation. On a quantitative basis, both of these fertilization rates approximate to $^1/_{10}$ pound of nitrogen fertilizer per year for a tree that is 1 to 2 years old. For a 3-year-old tree, the rate can be more than doubled ($^1/_4$ pound nitrogen fertilizer per year). Increase the dosage to $^1/_2$ pound nitrogen per year for a 4-year-old tree. Apply fertilizer around the drip line or in the path of irrigation water, being careful not to concentrate the fertilizer application in one area.

Fertilization of Fully Bearing Citrus Trees

Research at UC has contributed to the use of leaf analysis as a guide to planning fertilizer programs for commercial growers. Effective application methods and sophisticated models for determining when to fertilize have been developed for nitrogen, potassium, magnesium, and micronutrients. However, home gardeners do not use sophisticated analytical tools to determine which fertilizer to use or at what rate and when to apply them. The recommendations stated here should be interpreted as guidelines only because the recommendations are not based on quantitative, scientific leaf analysis of individual trees.

Nitrogen

Fully bearing, average-sized mature orange, lemon, and grapefruit trees (foliage diameter of 15–20 ft) should be fertilized at a rate of about 1 pound of actual nitrogen (N) per tree per year. Because ammonium nitrate (33-0-0) is 33% actual nitrogen, a mature tree needs 3 pounds of ammonium nitrate, or 5 pounds of ammonium sulfate (20-0-0), or 2 pounds of urea (46-0-0). (To determine the pounds of nitrogen in a given weight of fertilizer, multiply the weight in pounds by the percentage of total nitrogen stated on the label.) On soil with a pH below 6.0, ammonium sulfate is less advisable than other fertilizer types as a nitrogen source. For smaller or dwarf trees, fertilizer dosages should be reduced proportionally, according to the area of the tree canopy.

It is important to provide adequate nitrogen for flowering and fruit set to obtain good yields and fruit size. Broadcast nitrogen fertilizer onto the soil in spring. Some references recommend dividing the

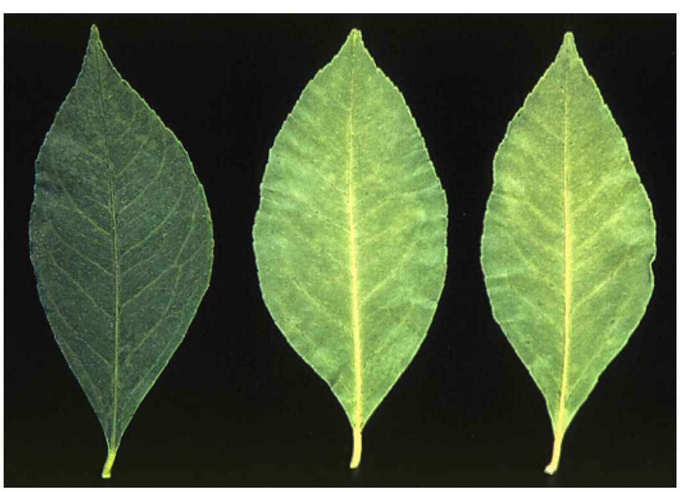
nitrogen fertilization requirement into thirds, giving a total of three doses per year (spring, summer, and early fall) to equal the total needed, but UC Cooperative Extension specialists point out that high levels of nitrogen fertilizer are to be avoided for oranges and grapefruit during the summer and fall, as they contribute to thicker rind, lower juice content, and regreening of mature Valencia oranges still on the tree during the summer. On the other hand, lemons respond positively to high nitrogen levels during the summer. Dividing the total amount of nitrogen fertilizer needed into more frequent, smaller applications made monthly or every other month, starting in spring when the trees start growing or flowering through the end of August or early September, best meets the continuing needs of the tree during the main periods of vegetative growth, flowering, and fruit development.

Water-soluble formulations of nitrogen fertilizer must be applied more frequently than slow-release types, which break down more gradually, releasing nutrients over many months. Thus, a single recommendation about when to apply nitrogen may not be appropriate for all citrus types, all fertilizer types, or all climates. UC farm advisors who specialize in citrus have noted that whether a homeowner fertilizes in late winter alone (in time to have nitrogen available for spring bloom), splits the dosage, or skips an entire year does not make a lot of difference for a mature tree. Nitrogen fertilizer should be scattered over the root area of the tree, which means under the tree and at least 1 to 2 feet outside the drip line. When sprinkler or drip irrigation is used, fertilizer should be applied to the area wetted by the irrigation system. The fertilizer should be watered into the soil with a good soaking of about 1 inch of water.

Figure 17.9

Grapefruit leaves with high (left), low (middle), and deficient (right) nitrogen concentrations. *Photo:* T. W. Embleton.

Figure 17.10



Nitrogen-sufficient (left) and -deficient (right) lemon leaves. *Photo:* T. W. Embleton.

Citrus trees in a lawn area will not receive adequate nitrogen when the lawn is fertilized. The area under the tree should be fertilized more often than the lawn to ensure adequate nutrition for the tree. The grass will take most of the nitrogen applied. When tree leaves show a slight yellowing (pale green color) (figs. 17.9–17.10), they can be sprayed with 1 ounce (2 heaping tsp) of urea (46-0-0) in 1 gallon of water. Foliar applications of urea are effective sources of nitrogen during spring growth and fruit-setting periods. Exceeding the concentration recommended can burn foliage. Apply very early in the morning or at sunset. Do not spray urea during hot weather.

If manure is used, apply it cautiously in the fall (September to October) because its potentially high salt concentration can burn citrus trees. Foliage may turn yellow and shoot tips may die from salt toxicity when the salts in the manure are carried into the root zone with irrigation water or rain. For these reasons, steer and chicken manure should be used sparingly.

Zinc

Zinc (Zn) deficiency causes mottleleaf (small terminal leaves with yellow mot-

tling between the large leaf veins) (figs. 17.11–17.12). Dieback of twigs may occur in severe cases. All nutrient deficiencies should be corrected quickly to prevent loss of yield and poor fruit quality. Foliar sprays and chelated formulations are available to combat the problem. Zinc is not taken up through the older leaves, and sprays must be applied during the spring or late summer vegetative shoot flushes to new leaves that are at one-half to two-thirds of their full size. Use approximately 1 heaping teaspoon of zinc sulfate (36% metallic Zn) in 1 gallon of water or approximately 4 teaspoons of zinc sulfate mixed with approximately 3 teaspoons of hydrated lime in 1 gallon of water. Treat for zinc deficiency at least 6 weeks before or after phosphate fertilizer application. Zinc and phosphate cannot be absorbed by plants at the same time. Read and carefully follow label directions.

Iron

Iron (Fe) deficiency manifests as a yellowing of leaf tissues between the veins (iron chlorosis), but the veins usually stay green (figs. 17.13–17.16). When the deficiency becomes severe, new leaves are completely yellow or yellow-white, and twig dieback may occur. Iron chlorosis is usually not a symptom of soil deficiency; instead, it indicates that the roots are not absorbing iron or making it available. It can be caused by overwatering, which leads to iron deficiency symptoms. The lack of oxygen that results from the excess water inhibits root function and iron absorption by plants. In addition to overwatering, iron chlorosis may be caused by high lime content in the soil.

Foliar sprays containing iron may be used to combat iron chlorosis. Wetting agents are added to the spray to promote good coverage. Several sprays of dilute

Figure 17.11

Zinc-deficient navel orange leaves. *Photo:* T. W. Embleton.

Figure 17.12

Zinc-deficient lemon foliage. *Photo:* T. W. Embleton.

Figure 17.13

Iron-deficient orange leaves. *Photo:* T. W. Embleton.

Figure 17.14

Iron-deficient grapefruit leaves. *Photo:* T. W. Embleton.

Figure 17.15

Iron-deficient lemon leaves. *Photo:* T. W. Embleton.

Figure 17.16

Comparison of iron-sufficient (left) and -deficient (right) lemon leaves and fruit. *Photo:* T. W. Embleton.

solution may be preferable to one spray at full concentration. Although chelated iron may correct many cases of leaf yellowing related to iron deficiency, chelated iron is very acidic and should be used on citrus with caution because it can cause leaf burn. Soil-applied iron slurries are longer-lasting than foliar chelate sprays. Micronutrient sprays are available that contain iron, zinc, and manganese. Since zinc and manganese deficiencies are more common than iron deficiency (one deficiency may actually mask others), a prudent course of action for fertilizing backyard citrus, which does not have the benefit of scientific leaf analysis, is to treat for several micronutrient deficiencies with a combination foliar spray. Follow label directions and apply to the new flush of leaves that are at two-thirds of their full size.

Magnesium and manganese

When magnesium (Mg) is deficient, older leaves turn yellow between the veins and drop (figs. 17.17–17.19). It is most noticeable in late summer and fall and in rainy climates. Application of magnesium sulfate (Epsom salts) can correct magnesium deficiency. When manganese (Mn) is deficient, young leaves turn light green between the veins. It is often more noticeable on a tree's north side. Manganese deficiency may occur in conjunction with zinc and iron deficiencies and can be difficult to distinguish. A soil-applied fertilizer containing a blend of micronutrients is recommended.

Phosphorus and potassium

Citrus fruit trees require little added phosphorus (P). Deficiency symptoms occur infrequently (fig. 17.20), and fruit size can be reduced with excess phosphorus fertilization (fig. 17.21). Apply about 1 pound of phosphate to the top 1 inch of soil around the tree's root system

Figure 17.17

Magnesium-deficient navel orange leaves. *Photo:* T. W. Embleton.

Figure 17.18

Magnesium-deficient lemon leaves (0.03–0.15% Mg). *Photo:* T. W. Embleton.

Figure 17.19

Magnesium-deficient leaves from lemon on Macrophylla rootstock. *Photo:* W. P. Bitters.

every 3 to 4 years. Potassium (K) fertilizer sources include chloride, sulfate, and nitrate forms. Chloride salts may injure citrus. If potassium appears deficient (figs. 17.22–17.24), soil applications of 2$^1/_2$ to 5 pounds per mature tree per year for 2 years are advisable. Response may be delayed by 2 to 3 years.

Boron

Excess boron (B) can cause leaf tips and margins to turn yellow and subsequently become necrotic (figs. 17.25–17.27). Lemons and grapefruit are more sensitive than oranges. If you suspect boron toxicity, check your irrigation water. If the level of boron is greater than 5 ppm, your water source may be the problem. Additional nitrogen fertilizer as calcium nitrate may alleviate boron toxicity.

Boron deficiency can occur when citrus is grown in low-boron soil and irrigated with low-boron water. Boron deficiency symptoms are most frequent when maturing trees are not irrigated sufficiently, which may occur, for example, when additional drip emitters are not added soon enough (fig. 17.28). Boron deficiency is easily corrected in drip irrigation by adjusting the number of emitters and by making a single application of $^1/_4$ to $^1/_2$ pound of boric acid (H_3BO_3) or borax ($Na_2B_4O_7 \cdot 10H_2O$).

Figure 17.20

Phosphorus-deficient lemon leaves. *Photo*: T. W. Embleton.

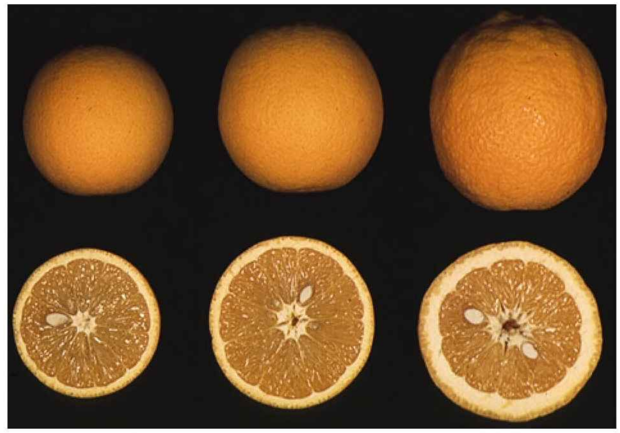


Figure 17.21

Valencia fruit from trees with leaf phosphorus concentrations that are, left to right, in excess (0.18% P), normal (0.13–0.14% P), and deficient (0.11–0.12% P, note rough peel). *Photo*: T. W. Embleton.

Figure 17.22

Potassium-deficient grapefruit leaves. *Photo*: T. W. Embleton.

Figure 17.23

Potassium-deficient lemon leaves. *Photo*:: T. W. Embleton.

Figure 17.24

Potassium-deficient lemon leaves and fruit. *Photo*: T. W. Embleton.

Figure 17.25

Symptoms of boron excess in grapefruit leaves (760–1,150 ppm B). *Photo:* T. W. Embleton.

Figure 17.27

Symptoms of boron excess in lemon leaves. *Photo:* W. P. Bitters.

Figure 17.26

Symptoms of boron excess in leaves of navel orange. *Photo:* T. W. Embleton.

Figure 17.28

Boron-deficient leaves (5 ppm) of navel orange on Trifoliate Orange rootstock. *Photo:* T. W. Embleton.

Fertilization of Container-Grown Citrus

The more frequent irrigation required in container-grown trees washes nutrients away from the root zone; thus, container-grown citrus trees require more frequent fertilization than citrus trees grown in the ground. To compensate, use a complete, slow-release fertilizer rather than a sole nitrogen source and follow the manufacturer's instructions. Micronutrients may also be deficient in container-grown citrus. Yellowing of foliage may not be due to nitrogen deficiency alone: iron deficiency is common in potted plants, and iron, zinc, or manganese deficiencies may cause chlorosis. Some complete fertilizers include chelated forms of these nutrients. Foliar sprays are most effective if applied during the spring or summer vegetative shoot flushes to leaves that are approaching one-half to two-thirds their full size. Container-grown citrus is also susceptible to boron deficiency because of constant leaching.

Pruning

Citrus trees need little pruning, unlike many ornamental trees and deciduous fruit trees in the home garden and landscape, which are pruned routinely every year.

During the first 2 years, select permanent citrus scaffold branches and perform limited pruning to establish the desired tree form and to remove suckers and water sprouts. Suckers are shoots of the rootstock cultivar that originate below the bud union on the trunk or from under-

ground. Suckers reduce the vigor of the tree and can eventually become dominant. Always prune them back to the point of origin. Water sprouts are vigorous upright scion shoots that grow in undesirable places, such as in branch crotches or along the trunk above the bud union. You may decide to prune lower branches off the ground for aesthetic reasons, or you may choose to leave these lower branches because they shade the ground, preventing weed growth, and they bear fruit that are easy to reach.

Ignore small irregularities in the canopies of young citrus trees. Left alone, citrus trees normally develop a relatively even, spherical shape as they mature. Lopsided trees caused by a dominant, fast-growing limb are the exception. Although pruning may force a lopsided tree into a more normal growth habit, the condition will usually correct itself if left unpruned, and the tree will assume a normal shape.

Pruning during the next 5 to 6 years should be limited to removal of occasional branches that interfere with the growth of a sturdy framework of scaffold limbs. Remove undesirable shoots that sprout following pruning when they are a few inches long and are still tender enough to be removed with a gloved hand. If undesirable shoots and water sprouts are allowed to grow, they deplete the tree of food reserves and necessitate more severe pruning later.

It is best to remove unwanted limbs where they originate or cut them back to a lateral. This reduces the sprouting of new buds in the area around the cut. Heading of a wanted limb may be done when needed to induce branching or to strengthen its growth if it is weak or willowy. Pruning cuts should be made as close to the vertical plane as possible, because the nearer to horizontal the cut, the greater the sprouting of new buds.

Lemon trees tend to need more pruning than oranges or grapefruit because lemon trees produce long, spindly shoots that are mechanically weak and easily broken. It is often necessary to remove some of these by thinning or to shorten others back to laterals to strengthen them. Lemon trees also send out strong laterals through the center of the tree. Without pruning, the interior of the tree fills with crossing limbs, which is undesirable. A good framework of scaffold branches helps prevent limb breakage. Branches at a wide angle to the central axis of the tree should be retained as scaffold branches. Those with a narrow angle should be removed. If early selective pruning of lemon trees is neglected, heavy cutting will be needed later, which delays and reduces yield. Lisbon lemon, especially, needs pruning, or it will become unmanageable. A systematic pruning program, begun when lemon trees are small, should be continued into maturity. Light, frequent pruning is advisable. Periodic thinning of unwanted branches and shortening of others to laterals result in the development of a low-spreading tree with fruit that are easy to harvest.

Pruning the Mature Citrus Tree

Bearing orange and grapefruit trees require little pruning. Most of the experimental work with citrus indicates that yield from healthy trees is reduced in proportion to the severity of pruning. For better pest control and ease of harvesting, limiting tree height may have merit, but if pruning is excessive, its advantages are outweighed by the loss of flowering and fruiting points on the tree. As a tree ages, the top branches are usually the first to decline in production and fruit quality. Light thinning of the top promotes the growth of new fruitwood, but pruning should not open a tree so much that exposed branches are sunburned. After pruning, if limbs are exposed to direct sunlight, they should be protected from sunburn by painting the exposed wood with white, water-based latex paint (diluted 1:1 with water) or with a Bordeaux powder to which water has been

added (make it a thick paint). When thinning the top of the tree, do not cut the branches to leave stubs. Instead, cut the limb back to another branch or lateral. Remove most deadwood and weak, nonproductive wood from the center of the tree. Retain vigorous shoots and bend them over to fill thinly foliated areas with fruitwood; however, remove them if the center of the tree is becoming filled with crossing limbs.

The skirt, or lower portion, of the tree bears a large portion of the fruit, and pruning there should be slight until the productive wood begins to decline. Nonproductive skirt branches should be removed by cutting from beneath, leaving the upper and newer foliage to replace what is removed. Known as undercutting, this helps ensure the bearing efficiency of the skirt. Pruning to hold trees to a given size requires judicious hand-pruning and results in some loss in yield.

Time of Pruning

Because time of pruning is not highly critical with citrus, trees are often pruned when other required cultural operations are minimal. Experiments have shown that the best results, from the physiological standpoint of the tree, can be expected if pruning takes place early in the spring after the danger of frost has passed and before the start of a new growth cycle. The rate of foliage regeneration is most rapid on spring-pruned trees and least rapid when trees are pruned late in the fall. Fall pruning also stimulates a late flush that is tender and more susceptible to frost injury during the winter. Winter pruning under temperature conditions that are not conducive to growth does not produce a vegetative flush. If pruning is done under temperature conditions conducive to growth, a vegetative flush will result.

The time of pruning may be restricted by the presence of mature fruit on the tree. Little problem is presented with navel oranges and winter grapefruit, when the crop is harvested before spring. With Valencia orange and summer grapefruit trees, both young and mature fruit are on the tree at the same time, and late-summer pruning after harvest may be preferred, when fruit are scarcest. In coastal areas, lemons are usually pruned after the last main summer harvest so that fewer nearly mature fruit are lost. Prune alternate-bearing trees in the early summer of the heavy crop year; removing some of the young, developing fruit will increase the size of the remaining fruit in the current crop and help increase production the next year by stimulating the growth of vegetative shoots in summer that will bear inflorescences and set fruit the following spring.

Pruning Injured Trees

Trees injured by frost, severe windburn, or rodents require special pruning. Periodic freezes of moderate to severe intensity occasionally occur in all of the major citrus-growing areas of the state. (See the section “Treating Freeze-Damaged Citrus Trees,” below.)

Windburn

Hot, dry winds occasionally injure citrus trees. Many of the defoliated limbs will recover; however, recovery is usually slower than from frost injury. Branches that do not recover should be pruned from the tree, taking care to minimize the loss of healthy foliage. Breakage from strong winds can occur. Young, vigorously growing lemons are most susceptible. When a broken limb bearing fruit is still attached, pruning can be put off until after harvest to allow the fruit to mature. A follow-up pruning may be needed to thin excessive regrowth.

Gopher injury

Trees damaged by gophers are usually healthy enough to recover unless they are badly girdled. When root damage is so extensive that remaining roots cannot supply adequate water for the scion, the canopy-root balance should be restored by pruning the scion. Gopher control is rec-

ommended because their damage can predispose trees to dry root rot.

Rejuvenation Pruning

In older orange trees, reduced tree vigor can result in small fruit and low yields. Loss of vigor is usually accompanied by dieback of twigs and small branches. Decline may be caused by a number of factors, either separately or in various combinations, such as tree age, low rainfall, faulty irrigation, salt accumulation in the soil and plant tissues, air pollution, and virus and pest problems. Rejuvenation pruning forces the tree to produce new fruitwood and ranges from a moderate thinning of the canopy to complete skeletonization of the tree. The latter removes all foliage and wood smaller than 1 inch in diameter, leaving only the main scaffold and adjoining branches. When older and weaker parts of the tree are removed, new buds sprout and new fruitwood is formed. Thus, the productivity of a healthy older tree will be restored. However, if the decline was due to another cause that has not been corrected, the effects of pruning will be temporary and the tree will decline again.

Care of Pruning Wounds

In California's dry climate, decay-producing organisms rarely enter citrus through pruning wounds. Research has shown that closing of large wounds is not hastened (and may be hindered) by covering with tree sealants or wound dressings. However, bark on limbs grown in the shade is susceptible to sunburn after pruning if it becomes exposed to direct sunlight; a few hours of exposure may cause injury. The exposed portion of limbs should be painted white with water-based latex paint (diluted 1:1 with water) or with a Bordeaux powder to which water has been added to make it a thick paint. Treatment of branches other than those exposed to the sun is unnecessary and may even be detrimental, since whitewash provides an excellent habitat for the development of red spider mites.

Care of Pruning Tools

When pruning citrus, protect yourself by using heavy gloves and goggles (many citrus cultivars have sharp thorns) and by using proper pruning tools. You need a good pair of hand pruners to remove stems with small diameters and a pruning saw to remove larger wood. If you have several citrus trees, equipment should be disinfested and sanitized by dipping tools into a 5% bleach solution (1 part household bleach with 4 parts water) before you start pruning and before moving to the next tree. To counteract the corrosive action of the disinfectant, clean pruning tools after use in a mixture of 2 teaspoons of emulsifiable oil in 1/2 cup of vinegar diluted with water to a total volume of 2 cups. This mixture should be shaken vigorously just before use.

Treating Freeze-Damaged Citrus Trees

Damaging freezes tend to occur in California citrus districts about once a decade. Certain techniques have been found to hasten tree recovery and to maximize desirable growth responses in cold-injured citrus trees.

Determine the Extent of Damage

Shoot and foliage injury usually becomes visible in a few days. Twigs and small limbs may show little or no signs of cold damage for 2 to 4 weeks. The rate at which freeze damage becomes apparent depends on the prevailing temperatures and humidity as well as the condition of the growth before and after exposure to frost. Except when trees are killed outright, it may be impossible to determine the severity of injury for several months or even for an entire year following a freeze.

Delay Pruning

Postpone corrective pruning until the full extent of damage can be determined. Pruning apparently dead wood when die-

back is still in progress can cause further, unnecessary dieback; delay corrective pruning until dieback due to frost has finished. If pruning is not postponed, some limbs that would have recovered might be removed unnecessarily, and a second pruning to rid the tree of undesirable brush and limb stubs is then necessary. Experience at UC has shown that early-pruned trees recover more slowly than do trees pruned later. There is no harm in waiting.

Remove Frozen Fruit

If the fruit has no value, remove it as soon as possible. The longer fruit remains on the tree, the greater it decreases the number of fruit in the next crop.

Trunk and Limb Treatment

The degree of injury provides a guide to the type of treatment required.

Light damage

No treatment is necessary when only foliage and small twigs are injured. No pruning except "dead brushing" should be done the ensuing season. All living foliage should be retained to nourish the root system and support the developing crop.

Medium damage

When a considerable part of the tree has been killed but the trunk and main limbs appear sound, the extent of damage can be determined only after several months. Do not prune until the full extent of the damage is visible. Save as much of the tree's framework as possible. Cut old limbs back below all serious bark injuries. Cut back to good, strong shoots. The distribution of new framework branches can be controlled to some degree by selection and light pruning during the summer. After injured branches have been cut back to new leaders, further pruning consists of gradually thinning excessive shoots over several years. These shoots crowd and interfere with growth and branching of the leaders forming the tree's new framework.

Severe damage

When most of the scion limbs have been killed, but the trunk shows little injury, no pruning should be done until the full extent of the damage is visible, usually after midsummer. At that time, remove the entire top of the tree by cutting below all large areas of injured bark. By this time, numerous new shoots will have grown from different locations on the trunk. From these, the new canopy of the tree must be formed. Select the uppermost good shoot and cut the old trunk off just above this shoot, sloping the cut downward away from the shoot. Then choose two or three other shoots properly spaced to form a new canopy and favor their growth by pinching back (removing) shoots that crowd them. All shoots should be left until a balance between root and canopy is established. Unnecessary shoots should then be removed gradually.

Very severe damage

When the tree has been killed and the injury extends well down the trunk but is followed by the appearance of strong sprouts above the bud union, a new trunk and canopy must be developed. They can be produced from one or more strong shoots originating from above the bud union. With young trees, it is usually best to favor one strong shoot. The top of the tree may then be removed, leaving the old trunk as a support to which the selected shoot may be tied. The shoot chosen for development should be favored and forced into growth by pinching back all others.

When the new scion growth has reached the size of a healthy 2-year-old orchard tree, the old trunk should be removed carefully by a cut starting just above the base of the new trunk and sloping downward. The surface of the cut should be allowed to dry. Do not apply wound dressing.

With large trees, recovery will be more rapid if several shoots are used to form the new canopy. There is no objection to

citrus trees with multiple trunks. When several shoots are used, it is best to remove the old trunk as soon as the extent of the freeze damage can be determined to minimize the risk of damaging the shoots with the saw. Do not treat cut surfaces. Allow all shoots to grow during the year following the freeze and until the new canopy is well formed.

Extreme damage

In most cases, trees killed to the bud union should be removed and replaced by new trees. If it is necessary to retain such trees, follow the directions above for very severely damaged trees. In addition, shoots selected for forming the new tree should be budded to the desired cultivar as soon as they are large enough to take a bud, about $^1/_4$ to $^3/_8$ inch in diameter. It is best to place the buds at a height of 18 inches to 2 feet because it allows shoots to grow around the base of the tree without shading the buds and interfering with their development.

Treatment of Freeze-Damaged Bark

Bark on the trunk of injured young trees may crack and curl. On injured trees of various ages, scattered patches of dead bark may appear on large limbs or on trunks even where no splitting occurs. When the extent of these injuries becomes clearly visible 2 or 3 months after a freeze, the dead areas of bark should be cut out smoothly and the exposed wood disinfested and painted to protect it from sunburn.

Protection from Sunburn after a Freeze

Protection of the trunk and large limbs from sunburn is advisable in warmer areas if regrowth has not occurred before hot weather arrives. It is necessary to protect only the parts of the trunk and large limbs that face south and southwest. Lemons are particularly susceptible to sunburning, and the tops of large horizontal limbs should be protected. For protection from sunburn, paint areas white with water-based latex paint (diluted 1:1 with water) or with a Bordeaux powder to which water has been added to make it a thick paint.

Irrigation after a Frost

Irrigate cautiously after a freeze. Water removed from the soil by the tree is lost through its leaves by transpiration. Thus, when leaves are damaged or destroyed by a freeze, the tree uses less water than under normal conditions until a new crop of leaves has developed. Irrigate only when soil conditions indicate a need. Determine soil moisture content by examining the soil or use tensiometers (see chapter 3, "Soil and Fertilizer Management"). Irrigations should be less frequent, and smaller amounts of water should be applied until trees have regained their ability to use normal amounts of water. In the case of severely damaged trees, this reduced irrigation requirement may last the entire growing season.

Fertilization after a Frost

The amount of fertilizer applied depends largely on the extent of damage. It is best to withhold fertilizer until the extent of damage is determined. Freeze-damaged trees do not respond better if heavily fertilized. In fact, more harm than good may occur. Slightly injured trees recover most rapidly and usually set crops in the spring following the freeze. Such trees require normal fertilization.

Severely damaged trees usually put forth a good deal of sucker or shoot growth that, through selection, will be used to rebuild the tree. Until the tree regains its full canopy, an imbalance exists between the root system and the canopy. Trees that have received regular fertilization or are growing on fertile soil have ample nutrients to satisfy the needs of their smaller canopies the first year following freeze damage. Fertilizer applied before the canopy has been reestablished may cause excessive sucker growth from the rootstock that must be removed. For severely damaged trees, reduce or omit

fertilization during the first season.

The imbalance between the root system and the canopy, together with vigorous sucker growth following a freeze, often results in micronutrient deficiencies that can retard recovery. Zinc is the element most likely to be deficient in citrus, but manganese and copper may also be at deficient levels. Zinc, manganese, and copper should be applied as foliar sprays when symptoms occur. With the rapid growth of new shoots, two or three applications may be necessary during the first season. Regular micronutrient foliar sprays containing the needed elements may be used. These symptoms can often result from excessive soil moisture, which should be checked and, if necessary, corrected by reducing irrigation.

Benefits of Mulching

Mulches have numerous benefits in the cultivation of citrus trees, particularly the reduction of urban waste disposal problems, the improvement in citrus tree root health, the suppression of nematodes and *Phytophthora* spp., and the improvement of soil physical properties by increasing the soil's organic matter content. Mulching was a common practice in citrus production until the 1940s, when inexpensive, easy-to-apply chemical fertilizers became readily available. Scientists in the past have shown that bean, barley, and alfalfa straw (green manures) increased navel orange production by up to 25% and conserved water use at the same time. Citrus trees treated with green manures have been shown to be superior in terms of tree size, yield, and fruit size to trees treated with animal manures. Recent research at UC Riverside has shown that yard waste (wood chips, leaves, and grass clippings) makes excellent citrus mulch. Several of the benefits of mulching citrus trees are discussed briefly below.

Reduction of Weed Problems

If mulches are at least 2 inches thick, they can reduce weed problems by preventing germination of weed seeds. Citrus trees, like other commodities, are more productive if they do not have to compete with weeds for water and essential nutrients. When weeds do grow, they should be hand-pulled because cultivation equipment can damage the tree's surface roots.

Conservation of Water

Mulches conserve water by reducing evaporation from the soil, reducing runoff and erosion, increasing the permeability of the soil surface, and increasing the water-holding capacity of the soil. Because mulches, especially grass clippings, increase soil moisture, irrigation should be reduced accordingly to prevent root diseases. At field capacity, mulched soil with high organic matter content has more water available to trees. Additionally, mulches reduce soil temperatures and reduce heat radiation, which can help the tree weather severe hot temperatures.

Improvement in Soil Physical Properties

Organic mulches can improve soil physical properties (soil structure and porosity) by increasing the soil's organic matter content, which results in aggregation of soil particles, increased pore size distribution, and better gas exchange (oxygen and carbon dioxide), facilitating better use of the top 12 inches of soil, the area where citrus tree roots are most active.

Improvement in Nitrogen Fertility

Organic mulches can eliminate or reduce nitrate contamination of groundwater by providing a continuous, slow release of nitrogen, reducing the need for nitrogen applied as chemical fertilizer. Typically, citrus groves in California have less than 1% organic matter in the soil. Maintaining high levels of organic matter in the soil is a primary factor in improving soil fertility. Increasing the organic matter content of the soil with mulches increases the soil's cation exchange capacity, which increases the availability of many nutrient elements to plant roots. Alfalfa straw has been

shown to be one of the most valuable mulches for citrus because it supplies nitrogen and conditions the soil.

Mulches with a high carbon-to-nitrogen ratio may cause a short-term initial nitrogen depletion, necessitating increased nitrogen fertilization, because of the increased populations of microorganisms produced during decomposition. However, the long-term benefit of decomposed mulch is an increased, slow release of nitrogen to the soil. Legume mulches and leafy plant material supply nitrogen and other nutrient elements essential to plants.

Control of Root Rot Diseases

Thick mulches applied to the soil surface can create conditions deleterious to pathogenic soil organisms, such as nematodes and *Phytophthora* oomycetes, which cause root rot diseases in both citrus and avocado. Mulches are especially effective in suppressing *Phytophthora* when the mulches are combined with applications of gypsum ($CaSO_4$).

Research has indicated that when the soil's organic matter content is kept in the range of 7% with organic mulches, the soil becomes suppressive to *Phytophthora*. Several mechanisms have been proposed to explain why mulches can reduce Phytophthora root rot in citrus and avocado:

Mulching increases the population of soil microbes that compete with or inhibit fungal pathogens.

Soil amended with alfalfa meal or other decaying organic matter is known to have higher concentrations of gases such as ammonia, which can inhibit *Phytophthora*.

Mulches create a natural litter layer favoring the proliferation of tree roots and disfavoring Phytophthora infection. The interface of the soil surface and mulch is a natural microenvironment where roots grow well but where *Phytophthora* spp. cannot survive. The fungus needs saturated soil conditions to release its zoospores, which must then swim to tree roots to cause new infections. Water drains so quickly from the mulch layer that saturated conditions may not last long enough for zoospores to be released and to swim to tree roots.

Chemicals produced during the decomposition of organic matter in mulched soil, such as ammonium ($NH4^+$), saponins, and nitrite ($NO2^-$), are toxic at low concentrations. They prevent propagule germination in *Phytophthora nicotianae* and retard disease development.

Organic matter can entrap fungal zoospores, preventing them from swimming to plant roots.

Soil gases and compounds released during organic matter decomposition in the mulch can increase the level of host (citrus) resistance in the roots to Phytophthora.

Yard Waste as a Citrus Mulch

One of the most compelling reasons to use yard waste as a citrus mulch is that it contributes to solving the problem of urban waste disposal. About 20% of solid waste dumped in landfills is estimated to be yard (green) waste. California's Integrated Waste Management Act mandates a significant reduction in the amount of waste that each county and city sends to landfills, with 1990 serving as the base year. Use of yard waste as a bioenhanced mulch on citrus trees in the home garden and landscape is also beneficial to citrus tree growth, particularly the health of tree roots.

Yard waste consisting of wood chips, leaves, and grass clippings was one of several mulches that UC Riverside scientists have shown to be beneficial to citrus culture, particularly the health of citrus roots. This is caused in part because the yard waste enhanced growth of two biological control agents, *Trichoderma harzianum* (a beneficial fungus) and *Pseudomonas fluorescens* (a beneficial bacterium), which are effective in suppressing Phytophthora root rot in citrus when they are present in the native soil.

The results of the research at UCR, which was conducted on six 12-month-old Troyer Citrange seedlings grown in the greenhouse, showed that the percentage of healthy citrus roots growing in the mulch treatments was positively correlated with the cation exchange capacity of the mulches and the populations of *Pseudomonas fluorescens* supported by the mulches. An important benefit of the yard waste tested at UCR was that the high carbon-to-nitrogen composition of the wood chips was offset by the high nitrogen concentration of the grass clippings, which reduced any temporary nitrogen shortage. The proportion of yard waste components with either high or low nitrogen content can be adjusted to optimize mulch efficiency.

Improvement in Soil Temperature

Mulches can reduce wide fluctuations in soil temperature by reducing the soil's absorption of heat. This can be beneficial to root growth, especially in young trees and in areas where summer temperatures are very high. Lower soil temperatures are also less favorable to some *Phytophthora* spp. When frosts are predicted, if possible, remove the mulch because bare soil can absorb more radiant energy than most mulches.

As discussed, you can use yard waste (wood chips, leaves, and grass clippings), straw (grain or bean), wood shavings, alfalfa meal, or any inexpensive source of inert organic material. If you use straw, beware of potential damage from field mice and rats; these rodents often make nests in the straw. Do not use mushroom compost or animal manure until the trees are at least 3 years old because these materials may contain excessive amounts of nitrogen (ammonia) or soluble salts that can be leached into the root zone and injure the trees' roots or cause tip burn of the leaves. Excessive amounts of ammonia released during decomposition of animal manures have also been shown to be detrimental to the growth of soil microbes that serve as biological control agents against disease-causing organisms.

Harvesting and Storage

Unlike fruits that continue to ripen after harvest, citrus fruit mature to eating quality only on the tree. In fact, citrus fruit do not undergo true ripening as defined by botanists, they simply mature. Judging eating quality may not be easy without sampling a few fruit. Rind color is not a reliable indicator. The rinds of oranges may have green pigmentation and yet the fruit may be edible, a situation that occurs when the weather remains hot and temperatures do not cool in the evening. Lemons and limes are ready for use when they are juicy; rind color may be green or yellow, although yellow fruit typically have more juice. Sampling fruit is a reliable method to determine eating quality, according to your individual palette. Some prefer their fruit sweeter. Others prefer a more acidic taste. Included in table 17.1 are harvesting periods for each cultivar in the citrus-growing regions in the state and comments about whether the fruit hold well on the tree. The timing and length of the harvest period depend on the cultivar and the climate in your area. Most citrus tends to hold on the tree longer in cooler climates than in warmer regions where night temperatures remain high.

Harvest most fruits by giving them a quick twist or by using hand pruners. Use hand pruners for loose-skinned mandarins because pulling the fruit may cause the rind to tear off around the stem.

Although the best place to store fresh fruit is on the tree, once it has been harvested it should be refrigerated, where it can last from 2 to 6 weeks. Before juicing citrus, fruit should be brought to room temperature, as it will yield slightly more juice. Before juicing, if you roll the fruit on a hard surface, pressing down firmly with the palm of your hand, you will be able to extract more juice. For best taste, use fresh

citrus juice promptly. Juices from navel and blood oranges develop off-flavors within a few hours; juices from other cultivars can be refrigerated for up to 36 hours before a significant loss in quality will occur. The juice of lemons, limes, and Valencia oranges can be frozen for up to 3 or 4 months. It may be convenient to store lemon and lime juice in ice cube trays to facilitate future use of small quantities in cooking.

Maximizing the Planting Area

Growing Dwarf Citrus Trees

Many dwarf trees grow to a height and width of about 8 feet and are usually globular in shape. The tree's environment—water quality, nutrition, planting density, soil texture, and temperature—influences its performance and size. True dwarfs are typically less than half the size of standard trees of the same cultivar. Thus, dwarfs of kumquats are considerably smaller than dwarfs of Valencia oranges, the former being 3 to 6 feet and the latter about 8 feet.

Dwarf trees yield full-sized fruit. Under good cultural conditions, they yield about 50 to 60% as much fruit as a standard-sized tree but in one-fourth of the space, which is beneficial to many home gardeners whose space is limited. Four dwarf cultivars can grow in the space of one full-size tree.

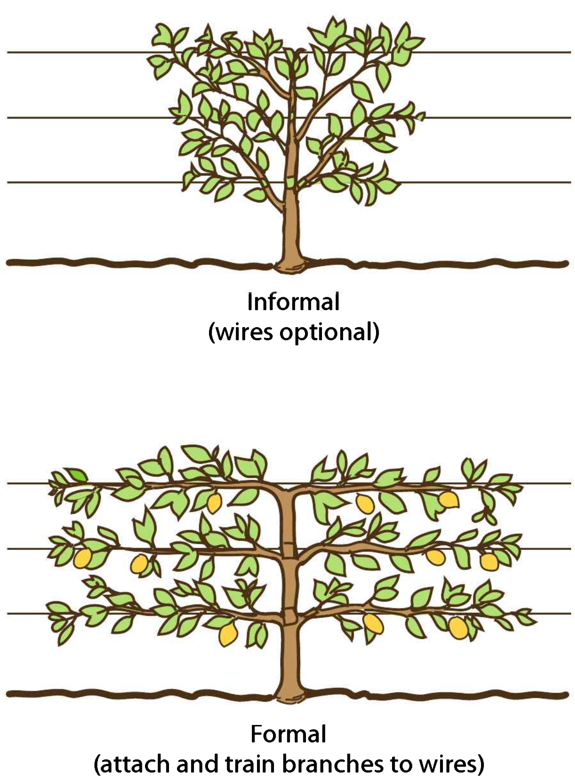
The only true genetic dwarf rootstock is Flying Dragon, a mutation of Trifoliate Orange rootstock. Scion cultivars grafted onto Flying Dragon rootstock grow to less than half the size of standard trees of the same cultivar. Other rootstocks have a dwarfing effect on certain fruiting cultivars; the resulting trees, known as semidwarfs, are about two-thirds of the standard size. Although not dwarfed, the growth rate is somewhat reduced. Almost all citrus cultivars sold in California are available dwarfed to some extent, with the exception of Eureka and Lisbon lemons, which are too vigorous for dwarfing. Eureka lemon scions are incompatible with Flying Dragon rootstocks. Some citrus cultivars are natural dwarfs, such as Improved Meyer lemon.

Citrus Espaliers

By selective pruning, the branches of citrus trees can be espaliered, that is, trained to grow flat against a wall or a framework, allowing you to grow fruit in a confined space such as a narrow bed or side yard. Standard and dwarf citrus trees can be espaliered; trees with an open growth habit and vining branches are the best candidates. According to the Sunset book *Citrus* (1996), some of the best choices for espalier are Eureka lemon, Nagami kumquat, Eustis limequat, Tarocco blood orange, and Chandler pummelo. Start with a young tree because it will be easier to train. You can design an informal espalier in which you plant the tree directly in

Figure 17.29

Two examples of espalier designs for citrus. *Source:* After Citrus 1996, pp. 26–27.



front of a structure, allow it to branch naturally, and prune any branches that stick out too far, or you can design a formal espalier, in which you train the tree into a precise geometric pattern (fig. 17.29). For the novice, an informal design is easiest. In a climate at the edge of the citrus belt, citrus espalier may have a distinct advantage. Training a citrus tree against a sunny, south-facing wall may supply enough heat for fruit to mature well and attain high eating quality, as well as increase the likelihood of surviving the winter.

Pests, Diseases, and Environmental Stresses

In comparison with other fruit trees grown in the home garden, such as apples and peaches, citrus trees have relatively few pest and disease problems if they receive good care. Certain cultivars are more susceptible to pests and diseases, but healthy trees that are irrigated and fertilized properly should have less pest damage. Since lemon trees set fruit throughout the year in the coastal climate zone, fruit are at various stages of development year-round, which can present some special pest management problems. But if you are willing to overlook an occasional chewed leaf or rind blemish and focus on the more serious enemies that can compromise the overall health of your trees, your pest control program at home will likely be minimal.

Common Pests

Table 17.4 lists the most common citrus insect and mite pests, diseases, and environmental stresses and gives information about what the symptoms look like, the probable causal agent, and some comments about control. A comprehensive reference on this subject is UC's *Integrated Pest Management for Citrus*, 3rd edition (Dreistadt 2012). UC's *Pests of the Garden and Small Farm* (Flint 1998) also has excellent information and color photographs of pests, diseases, and environmental stresses on citrus and other commodities. Current, detailed information on citrus pests and diseases, with color photographs for identification, and information on their control is also available on the UC IPM website, ipm.ucdavis.edu.

A more technical UC reference on citrus pests and their management is the UC IPM Citrus Pest Management Guidelines, ipm.ucdavis.edu/PMG/selectnewpest.citrus.html, which is updated frequently and intended to be used in conjunction with *Integrated Pest Management for Citrus*. For each citrus pest, the guidelines list the scientific name of the pest and provide a user-friendly but technically accurate discussion describing the pest and its life cycle, damage caused, cultural control measures, biological control measures, selectivity, organically acceptable control methods, monitoring techniques, and when to treat, along with specific pesticide treatments, their recommended rates, and minimum days to treat before harvest.

Citrus is susceptible to fungal, viral, and bacterial diseases, but if you purchase healthy trees with rootstocks selected for improved disease resistance (see tables 17.2–17.3) and employ preventive measures to reduce or eliminate conditions favoring these pathogens, you should not expect to have many problems. The damage potential of many citrus diseases depends on the rootstock and scion, soil conditions, and water management practices of the gardener.

Presently, one bacterium, several viruses, a mollicute (bacteria-like organism lacking a cell wall), and a few fungi cause the major infectious diseases in California citrus (see table 17.4). Fungal and bacterial diseases of citrus cause more losses in the Central Valley because of the long, wet winters than in other climate zones in the state.

A devastating new disease to California, huanglongbing (also called citrus greening disease or yellow dragon disease) is

Table 17.4.

PROBLEM DIAGNOSIS FOR CITRUS

What the problem looks like	Probable cause	Comments
Round, red-brown scales on fruit, leaves, and twigs. Initially, leaves will have yellow halos around red-brown scales. Eventually, leaves may yellow and drop and twig dieback may occur. Damage most visible in late summer and early fall. Reduces tree vigor.	California red scale *(Aonidiella aurantii)*	An armored scale insect. Armored scales suck plant tissue and can overwinter on citrus. Related to yellow scale *(A. citrina)*. Can be distinguished from yellow scale under a microscope. One of the most important pests in California citrus. Widely distributed. Lemon is the most susceptible, followed by grapefruit, Valencia, navel, and mandarin oranges. Unlike soft scales, does not secrete honeydew. Natural enemies (parasitic wasps—*Aphytis* and *Encarsia* spp.) can provide good control in many parts of California. Chemical treatment may be needed in San Joaquin Valley.
Black film on leaf surfaces.	sooty mold fungus	Most active in cool, moist conditions. Fungus grows on honeydew excreted by aphids, mealybugs, scale insects, and whiteflies. Sooty mold should be washed off leaves because it can reduce photosynthesis and tree productivity if prolonged. Cosmetically unappealing on fruit; usually no serious harm, but wash it off.
Fruit and leaves covered with honeydew and sooty mold. Scales on leaves and twigs, rarely on fruit. Tree vigor may be reduced.	various soft scales: citricola scale *(Coccus pseudomagnoliarum)* brown soft scale *(C. hesperidum)* black scale *(Saissetia oleae)*	Soft scale insects suck plant juices from leaves and twigs. Citricola is more serious in San Joaquin Valley than in southern California. Natural enemies and oil sprays are effective controls. Keep ants out of trees because they protect scales from natural enemies. *Metaphycus* parasites can be purchased and released for additional control. Time treatments to target new brood right after hatching.
Distorted, curled leaves, honeydew, and sooty mold.	aphids: spirea aphid *(Aphis citricola)* cotton or melon aphid *(A. gossypii)*	Insects suck sap from tender, new growth. Honeydew provides a medium for growth of sooty mold fungus. Control needed only for heavy infestation on young trees. Dislodge with jet streams of water or use insecticidal soap or oil sprays may be available: see the UC IPM website, ipm.ucdavis.edu, for more information; see also comments for sooty mold fungus, above.
Fruit and leaves covered with honeydew and sooty mold. Tiny whiteflies fly out when branches are disturbed. Immature insects look like transparent spots.	whiteflies: woolly whitefly *(Aleurothrixus floccosus)* citrus whitefly *(Dialeurodes citri)* ash whitefly *(Siphoninus phillyreae)*	Whiteflies excrete honeydew, which attracts ants and promotes growth of sooty mold. Whiteflies also suck phloem sap from leaves, causing leaves to wilt and drop. Adults have mealy, white wax on their wings and bodies. Natural enemy parasites usually provide control. Eliminate ants and control dust; they interfere with natural enemies. Chemical controls not effective.
Fruit and leaves covered with honeydew and sooty mold. Cottony secretion on leaves and twigs. Scales extract plant sap from leaves, twigs, and branches, reducing tree vigor.	cottony cushion scale *(Icerya purchasi)*	Newly hatched nymphs are red and found on leaves and twigs. Older scales are on twigs and covered with a cottony secretion. Eggs are in a fluted white egg sac about 1/2 in long. Becomes a pest only when its natural enemies (Vedalia beetle and the parasitic fly *Cryptochaetum iceryae*) are destroyed by insecticides. Reestablish natural enemies and avoid use of insecticides. In the 1890s, this pest threatened the entire citrus industry in southern California, but success with natural enemies brought it under control. Today, light infestations occur every summer in the San Joaquin Valley because of temporary destruction of the pest's natural enemies. Occurs on a wide cultivar of fruit trees, nut trees, and ornamentals.

Table 17.4. cont.

PROBLEM DIAGNOSIS FOR CITRUS

What the problem looks like	Probable cause	Comments
Fruit and leaves covered with honeydew and sooty mold. Mealybugs present.	mealybugs (*Pseudococcus* or *Planococcus* spp.)	Soft, oval, distinctly segmented insects covered with a mealy white wax. Adults about 1/8 to 1/4 in long. Mealybugs extract plant sap, reducing tree vigor. If a cluster of mealybugs feeds along a fruit stem, fruit drop can occur. Natural enemies usually control mealybugs, but only when ants are also controlled. At home, you can remove mealybugs by hand, hose them off with water, or apply registered pesticide. A predator, the mealybug destroyer, is available commercially for release.
A ring or partial ring of scarred tissue on fruit rind near stem end. Young leaves may be deformed and scarred.	citrus thrips *(Scirtothrips citri)*	A tiny yellow insect about 1/25 in long. Very active. Damage is primarily aesthetic, cosmetic. Ignore this pest in home gardens. Botanical pesticides are used in commercial orchards. Irrigate adequately because thrips prefer water-stressed plants. When monitoring, you must be able to distinguish this pest from flower thrips, which feed on flower parts but do not damage citrus (see Dreistadt 2012).
Surface feeding or holes in blossoms, leaves, or young, developing fruit. Chewed leaves.	orangeworms	Collective term for all moths and butterflies that are pests of citrus in the larval (caterpillar) stage. Trees can tolerate some damage to foliage and loss of blossoms. Orangeworms can cause substantial damage by feeding on fruit. Examples of orangeworms are the citrus cutworm and leafrollers (see below), the western tussock moth, citrus looper, and orange tortrix. Larvae of the major orangeworms are difficult to distinguish. All produce webbing except the citrus cutworm.
Surface feeding or holes in blossoms, leaves, or young, developing fruit. Chewed leaves.	citrus cutworm *(Xylomyges curialis)*	Brown to green, smooth-skinned caterpillar with a prominent white stripe on each side. Curls up when disturbed. Develops into moth. A problem primarily in the San Joaquin Valley. Damage occurs in spring. Natural enemies (parasitic wasps) are often effective. *Bacillus thuringiensis* is also effective. Not a problem in desert or coastal areas. Citrus cutworm is a type of citrus orangeworm, a common name for all moths and butterflies that are pests on California citrus.
Leaves have semicircular areas chewed out of the leaf margins. In later stages, trees are weakened or killed due to root damage.	citrus root weevil, Diaprepes weevil *(Diaprepes abbreviatus)*	The large (3/8–3/4 in long) colorful (gray and yellow to black and orange-striped) adult feeds on the leaves of all citrus cultivars and more than 200 other plant species. The adult lays clusters of eggs in leaves that are folded and glued together. Newly-emerged larvae drop to the soil and the grub-like larvae feed on the roots for several months. Diaprepes weevils have established in citrus along the coast in San Diego, Orange, and Los Angeles Counties. Parasitoids imported from Florida are being released by UC farm advisors in infested groves in hopes that biological control can be established.
New leaves have holes and are webbed and rolled together. Caterpillars also feed on buds and developing fruit, often rolling and webbing fruit and leaves together.	leafrollers: fruittree leafroller *(Archips argyrospilus)* omnivorous leafroller *(Platynota stultana)* orange tortrix *(Argyrotaenia citrana)*	Fruittree leafroller attacks citrus, apples, almonds, pears, and stone fruits. It has the same geographical distribution as the citrus cutworm, and the two species often occur together and have one generation per year. Insect damage to the fruit may result in decay. Most damage occurs in spring and early summer. Omnivorous leafroller has many generations per year, and damage can occur throughout the growing season. Translucent caterpillars. General sanitation and natural parasites are effective controls.
New leaves have shallow tunnels or mine trails, with a central trail of frass within the tunnel, on the upper or lower leaf surface, causing the leaves to curl or look distorted.	leaf miner *(Phyllocnistis citrella)*	The adult is a tiny moth less than 1/8 in long with silver and white iridescent forewings with brown and white markings and a distinct black spot on each wing tip. Wingspan is only about 1/4 in. Larvae cause the damage by feeding in the tunnels, leaving a distinctive thin central trail of frass (excrement) within the tunnel. The pupa is found in curled edges of the leaf. Mature trees (older than 4 years) can usually tolerate leaf damage, but such damage may retard the growth of younger trees. Natural enemies may be present so do not use a broad-spectrum insecticide to control. The insect is attracted by the young leaves on new flushes of growth: prune in winter, remove water sprouts and suckers, and do not apply nitrogen fertilizer when leaf miner populations are high.

Table 17.4. cont.

PROBLEM DIAGNOSIS FOR CITRUS

What the problem looks like	Probable cause	Comments
Fruit or stems have shallow tunnels or mine trails without a central trail of frass, not found on new leaves.	peel miner *(Mamara gulosa)*	Larvae of this small moth form mine trails on the surface of the fruit, especially grapefruit, pummelo, and smooth-skinned navels, and on the stem. The damage, which can cover 5–80% of the fruit surface, is purely cosmetic. The best long-term control of peel miner is by the many native pests that attack it and by not planting susceptible cultivars.
Holes in leaves and fruit; slimy trails.	brown garden snail *(Helix aspera)* gray garden slug *(Agriolimax reticulatus)*	Brown garden snail is about 1 in in diameter with distinct color pattern; gray garden slug is a snail relative that lacks a shell. Both pests are most active at night and early morning when it's damp. Both can be managed by skirt pruning and trunk treatment. Where legal, it is controlled by predatory decollate snails *(Rumina decollata)*. Use wooden boards with cleats for monitoring. Remove collected snails and slugs daily. See the UC IPM website for control recommendations, ipm.ucdavis.edu.
Ants feeding on twigs, bark, leaves, and honeydew excreted by other insect pests. Argentine worker ants travel in distinct trails.	Argentine ant *(Iridomyrmex humilis)* Southern fire ant *(Solenopsis xyloni)*	Ants feed on honeydew excreted by soft scales, mealybugs, aphids, cottony cushion scales, and whiteflies. Ants can disrupt biological control of these pests. Control ants by denying access to the canopy. Apply a band of sticky material to base of trunk, which mechanically impedes ants. Prune the canopy up (above 30 in off the ground) so that ants cannot get into the tree without climbing the trunk.
Leaves and green fruit have a pale yellow stippling. No webbing. Bright red globular eggs laid on bark or leaves.	citrus red mite *(Panonychus citri)*	A barely visible red mite (use hand lens) found mostly on young leaves. Can be a problem on patio trees and indoor house plants. Oil sprays between Aug and Sep will control problems in most areas. Natural controls should be sufficient in unsprayed backyard trees. Weekly washings with soapy water are an effective control, but they will not eliminate the problem.
Oddly misshapen and distorted flowers, fruit, and leaves. Primarily a problem on lemons in coastal areas.	citrus bud mite *(Eriophyes sheldoni)*	Very small, barely visible, elongated, yellow mite with only four legs that appear to be coming out of their heads. Smaller than red mites. Petroleum oil sprays during May–Jun or Sep–Nov can control. Natural predators are also effective. To detect bud mites before damage occurs, check buds on green angular twigs from midspring to fall.
Destroyed rind cells, causing russeting on mature oranges and silvering of rind tissue on lemons.	citrus rust mite *(Phyllocoptruta oleivora)*	Very small, barely visible mite, deeper yellow than bud mite but similar size. A sporadic pest in coastal citrus plantings. Called silver mite on lemons and rust mite on oranges. Most damage occurs from late spring to late summer. Monitor by looking for rust mites on foliage in early spring using a 10× to 14× hand lens. On lemons, check fruit for scarred rind tissue. No effective natural enemies are known. Control dust. If treatment is required, see the UC IPM Citrus Pest Management Guidelines at the UC IPM website.
Maggots inside fruit pulp.	fruit flies: oriental fruit fly *(Dacus dorsalis)* Mediterranean fruit fly *(Ceratitis capitata)* Mexican fruit fly *(Anastrepha ludens)*	Female fruit flies lay eggs in the fruit rind. Importation of these pests from Mexico and Hawaii is a constant threat. They attack citrus, other subtropical fruits, and deciduous fruits. Maggots develop inside the fruit pulp, destroying the edible juice vesicles. Localized infestations have occurred several times in southern California in recent years. Immediately contact your local county agricultural commissioner's office if you suspect fruit fly infestation.
New leaves have tiny, white dust-like flecks (insect eggs); tiny, bright orange insect larvae with red eyes; and white, curly, waxy string (insect exudate).	Asian citrus psyllid *(Diaphorina citri)*	A tiny (⅛ in) aphid-sized mottled brown insect that lays its eggs on citrus and closely related ornamental plants. The nymphs and adults feed and lay eggs primarily on the new citrus leaf growth, producing curling, waxy honeydew. This insect pest is extremely dangerous because it can carry the organism that causes huanglongbing, a disease that can kill a citrus tree in 3–5 years. The symptoms for huanglongbing are described below. If you think you have this insect, go to the Citrus Research Board website for pictures of the Asian citrus psyllid (ACP) and directions for reporting possible sightings: californiacitrusthreat.org/. See UC IPM website for management information, ipm.ucdavis.edu.

Table 17.4. cont.

PROBLEM DIAGNOSIS FOR CITRUS

What the problem looks like	Probable cause	Comments
One or more of the following symptoms: (1) yellow shoots standing out from the canopy; (2) small, upright, thickened chlorotic leaves, some with green islands and some resembling nutrient deficiencies especially zinc deficiency; (3) leaves with asymmetric blotchy mottling that crosses leaf veins; (4) small, lopsided, bitter-tasting fruit with small, dark aborted seed.	huanglongbing, citrus greening disease, yellow dragon disease (*Candidatus Liberibacter asciaticus* and related spp.)	The bacterium causing this disease has been found in a limited area of southern California, but it is critical that every person growing a citrus tree be diligent in looking for the symptoms of huanglongbing and the insect that vectors the disease-causing bacterium, the Asian citrus psyllid (ACP), described above. Restricting the spread of the Asian citrus pysllid and huanglongbing depends on backyard growers. It is extremely important to not move trees, leaves, fruit, shoots, or budwood from ACP- and huanglongbing-infested areas to other areas within California. It is equally important not to bring citrus or citrus relatives into California from other parts of the United States or world. The Citrus Clonal Protection Program (CCPP) can assist you in bringing citrus cultivars legally and safely into California (ccpp.ucr.edu). Plant trees from reputable, licensed California nurseries to avoid getting diseased plants. Learn how you can help protect California citrus at californiacitrusthreat.org/. Learn more about these pests at the UC IPM website, ipm.ucdavis.edu/.
Leaves turn pale green to yellow, especially in winter and spring (figs. 17.9–17.10). No mites present.	nitrogen deficiency	Symptoms may appear in spring when soil temperatures are cold and trees are not able to take up nutrients despite adequate amounts in the soil. Check to see that fertilizer requirements are met. Can apply foliar nitrogen as urea to increase bloom set and yield.
Leaves turn yellow and drop. No mites present. Abnormally low number of blossoms.	overwatering	Decrease irrigation frequency. Avoid planting ferns, annual flowers, or plants that need lots of water near citrus trees.
Leaves turn yellow with yellow veins and drop. Beads of sap ooze from trunk lesions. Gumming is more pronounced in spring. Inner bark is brown and gummy, but the discoloration does not extend into the wood. Bark can dry, harden, and crack. Overall the pathogen girdles the tree, which declines due to disruption of transport of water and nutrients.	gummosis (*Phytophthora* spp.)	When infection is just above the bud union and spreads higher up on the trunk and main branches, it is called gummosis. Caused by the oomycetes *Phytophthora nicotianae* (formerly named *Phytophthora parasitica*) or *P. citrophthora*, which infect the tree trunk. Keep trunk dry. Do not allow sprinkler water to hit the trunk. Scrape away all diseased bark (tan, discolored bark and wood). Be sure to disinfest the knife with 10% bleach between cuts. Leave a 1-inch buffer strip. Allow wood to dry. Use a propane torch to burn the lesion. Repeat if infection recurs. Do not mound soil around trunk, and keep water away from trunk. Improve ventilation by removing branches that touch the ground. Avoid injuring bark with lawn mowers, weed whackers, and pruning tools, since wounds predispose the tree to infection.
Leaves turn yellow and drop. Root bark of infected roots slides off easily when pinched. Feeder roots destroyed. Symptoms may be difficult to distinguish from nematode, salt, or flood damage.	root rot (*Phytophthora* spp.)	Caused by the oomycetes *P. citrophthora* and *P. nicotianae*, which can also cause gummosis of the tree trunk. These fungi-like organisms are soilborne and infect the root system, causing a slow decline in tree health. Survive in soil a long time. Disease can occur when trees are overirrigated or soils are poorly drained. Shorter, less frequent irrigations may help if damage is not severe. Avoid waterlogging. If damage is severe, remove tree. Use tolerant rootstock. Trifoliate Orange, Troyer/Carrizo Citrange and C-35 Citrange rootstocks are tolerant (tables 17.2–17.3). Do not plant citrus in lawn, where it will be watered too frequently.
Ripe fruit turns light brown and becomes soft. Water-soaked spots on rind become soft and turn brown. Pungent odor.	brown rot (*Phytophthora* spp.)	Caused by the oomycete *P. citrophthora*, which causes gummosis and root rot but infects fruit in this disease. Occurs primarily on fruit borne near the ground during wet weather. Spores on the ground get splashed onto fruit on lower branches by rain or irrigation water. Remove diseased fruit. Consult ipm.ucdavis.edu for management recommendations.
Fruit decreased in size, yellowed leaves, twig dieback, general loss of vigor.	citrus nematode *(Tylenchulus semipenetrans)*	Microscopic, wormlike pest. Nematodes feed on citrus roots. Belowground symptoms include poor growth of feeder roots. May occur in conjunction with Phytophthora root rot. Plant trees with resistant rootstocks (see table 17.2).
Poor growth, dieback of shoots. Small, yellowing leaves and premature leaf drop. In winter, may be mushrooms at base of infected trees a few days after a rain.	Armillaria root rot *(Armillaria mellea)*	Also known as oak root fungus. Symptoms may not appear until fungus is well established. Once symptoms appear the disease has probably already spread to roots of surrounding trees. Pathogen invades roots and can destroy entire root system. It also moves into the scion. Rarely a problem in desert areas because fungus requires cool, moist soil for development and spread. Management relies on preventing infection in new trees. Once infection is apparent, it is very difficult to save a tree. If your planting site may be infested, fumigate it before planting. Remove and burn infected trees and neighboring healthy trees. Note: Not all mushroom growth indicates presence of *Armillaria*.

Table 17.4. cont.

PROBLEM DIAGNOSIS FOR CITRUS

What the problem looks like	Probable cause	Comments
Internal black rot in navel orange fruit. Rot starts at stem end, extends into core. Can occur on lemons in storage.	Alternaria rot *(Alternaria citri)*	A fungus disease. Also known as black rot on navels. More of a problem when the navel is split. Preventing stress reduces susceptibility. No chemical control.
Tan to reddish-brown spots on Valencia orange, lemons, grapefruit.	Septoria spot (*Septoria* spp.)	Occurs primarily in the San Joaquin Valley and interior districts of Southern California during cool, moist weather. Spores are spread in dew or rainwater. Anthracnose (*Colletotrichum gloeosporioides* or *Alternaria* spp.) can occur as secondary infections on lesions caused by *Septoria*. Home growers do not need to control.
Whitish mycelium on fruit; blue and/or green spores appear on fruit.	blue mold *(Penicillium digitatum)* green mold *(Penicillium italicum)*	May occur on injured fruit in the field but more often is a storage, postharvest disease. Early infections are almost impossible to detect. Easily recognizable when whitish mycelium and blue or green spores appear. Both types may occur together. To reduce infection, do not pick wet fruit and handle fruit carefully during picking. Immediately discard infected fruit and wash all stored fruit nearby in soapy water. Do not harvest fruit from the ground.
Small, lopsided fruit; stunted growth; small leaves held upright, not flat; inferior, off-bloom fruit.	stubborn disease *(Spiroplasma citri)*	A disease of the vascular tissue caused by a mollicute (bacteria-like organism lacking a cell wall). Afflicts primarily sweet orange, grapefruit, and tangelo trees in hot inland areas of Southern California and the desert. No control available. Transmitted by several species of leaf-hoppers that have many alternative hosts among the native vegetation species. Infected young trees have low yield of small fruit, which are frequently lopsided. Stubborn symptoms can be confused with those of huanglongbing, so it is very important to carefully inspect citrus trees in California. See the above entry on huanglongbing in this table and chapter 6, "Plant Pathology", for information on spiroplasmas.
Stunted growth, light green foliage, poor growth flushes, leaf cupping, vein clearing, stem pitting and some leaf drop. Symptoms are highly variable depending on the host species, environment, and severity of the virus isolate. Mandarins are tolerant to tristeza. Oranges, limes and lemons are usually symptomless, but may react to severe isolates. Two important symptoms are related to tristeza. Quick decline of sweet orange, mandarins or grapefruit when grafted on sour orange rootstock and stem pitting of limes, grapefruit and pummelos, which are more sensitive than sweet orange cultivars. Young infected trees bloom early and abundantly. Large harvest of small fruit especially from infected trees expressing stem pitting.	Citrus tristeza virus (CTV)	Use tolerant rootstocks (i.e., trifoliate and trifoliate hybrids) when planting new trees. Rootstocks used today (table 17.2) are tolerant. No control available. Remove infected trees; sanitize area. Use certified clean budwood tested for CTV from the UCR's Citrus Clonal Protection Program (http://ccpp.ucr.edu/).
Scaling, flaking of bark on scion cultivar. Patches of bark on trunk, scaffold branches show small pimples or bubbles that later enlarge and become loose scales.	Citrus psorosis virus	Graft-transmissible disease, generally only found in old citrus plantings. Infected trees, mostly orange and grapefruit, slowly decline. Gumming can occur around lesions. Budwood tested for disease from the UCR's Citrus Clonal Protetion Program prevents damage (http://ccpp.ucr.edu).

Table 17.4. cont.

PROBLEM DIAGNOSIS FOR CITRUS

What the problem looks like	Probable cause	Comments
Excessive fruit drop, especially on young trees.	sudden temperature change (heat wave at fruit set) too much or too little moisture nutrient deficiency	Nutrient deficiencies can be identified by the pattern of leaf yellowing (chlorosis) and by noting whether it occurs on new or old foliage. When problem is identified, adjust fertilization program to add needed nutrient in form that roots can extract or leaves can take up as a foliar spray (chelated micronutrients). Nutrient deficiencies can also result from too little water. If lack of water is a problem, add additional drip emitters as citrus tree grows and root system expands. *Nitrogen deficiency:* Starts with older leaves near bottom of tree and foliage turns a uniform yellow (see figs. 17.9–17.10). *Zinc deficiency:* Young leaves are abnormally small with yellow blotches between the veins (see figs. 17.11–17.12). Symptoms are most obvious on the south side of the tree. Use foliar spray. *Iron deficiency (rarely seen outside of desert):* Young leaves turn yellow between the veins; veins stay green (see figs. 17.13–17.16). Common in alkaline, poorly drained, overwatered soils. Add chelated iron, not foliar sprays. *Manganese deficiency:* Young leaves turn a lighter green between the veins. Often more noticeable on tree's north side. May occur with iron and zinc deficiencies. *Magnesium deficiency:* Older leaves turn yellow between veins and drop (see figs. 17.17–17.19). Most noticeable in late summer and fall and in rainy climates.
Bark dries, cracks, and may lift in thin strips. Droplets of gum also appear under loose bark. Known as shelling.	exocortis (citrus exocortis viroid)	Exocortis spreads on infected budwood and contaminated propagation tools. Has been greatly reduced in California because of strict regulations on budwood sources. Widespread in older plantings. Scion cultivars budded to rootstocks of trifoliate orange are known to express the symptoms of exocortis. UCR's Citrus Clonal Protection Program, ccpp.ucr.edu, provides budwood tested for exocortis to nurseries, which can be grafted onto susceptible rootstocks, such as Trifoliate Orange and its hybrids. Heat does not kill the viroid. Remove infected trees because pruning clippers can transmit disease unless disinfested with a 1–5% bleach solution (1 part household bleach with 1–3 parts water; solution should appear light yellow and have the typical bleach odor). This disease is latent in most citrus. Sensitive species include trifoliate orange, Rangpur lime, and some citrons and lemons.
Brittle wood peels off in patches. Fruit rind develops tough, brownish spots and fruit may dry out. Leaves may have brownish spots, commonly seen on southwest portion of canopy.	sunburn	A problem in hot, sunny areas. For newly planted trees, wrap the trunk in white cardboard or use whitewash or flat latex paint in white or a light brown color that blends with tree trunk. Ruby Red grapefruit is prone to sunburn damage on leaves and fruit.
Random fruit scarring. Scarring does not form a ring around the stem end, as with damage from thrips.	wind abrasion	Minor problem. Create a windbreak or plant trees in a nonwindy area. High winds can also cause premature leaf drop.
Leaves, twigs look water soaked, then wither, darken. Leaves may drop quickly or persist on tree. When fruit freezes, flesh dries out and brownish pits (ice marks) may form on the rind. Branches die back and bark splits in severe cases.	frost damage	Wait before treating frost damage. Allow the tree time to recover before removing frost-killed wood. After new growth appears in early spring, wait for any dieback, then cut back to live wood (identified by a green layer just under the bark). Pruning cuts will heal naturally, so there's no need to paint them.
Navel oranges split. Small percentage of fruit affected.	late growth spurt; rapid uptake of water by juice vesicles	Exact cause unknown. Problem may occur in the fall when the rind does not expand as fast as the underlying juice vesicles during a late growth spurt, causing splits. More common in years with cooler-than-normal summer months followed by warmer-than-normal fall months. Problem may also occur in winter or spring in response to heavy irrigation or rain following a period of limited irrigation or rain.
Puffy rinds in juice oranges and mandarins.	old fruit	Exact cause unknown. Problem may occur as fruit age and is greater in heavy crop years. Potassium fertilizer in early spring (Feb–Mar) can mitigate problem if it occurs annually.
Yellow leaves.	various	Excessive watering, nutrient deficiency, girdling of trunk by rodents, root diseases, sunburn, and high lime content of soil, causing iron deficiency, may result in leaf yellowing. Some grapefruit tree leaves develop a yellow color in winter months. This is genetic, particularly in young Ruby Red trees, and not a symptom of a problem.

Source: Adapted from Flint 1998, pp. 246–247.

caused by a bacterium that has been found in a limited area in southern California and is widely present in citrus trees in Florida and in Mexico. The vector of huanglongbing, the Asian citrus psyllid, is present in citrus-growing areas of California. The status of this new disease and its vector are ever-changing, and current information about them can be found on the UC IPM website, ipm.ucdavis.edu, and at the California Department of Food and Agriculture website, cdfa.ca.gov/phpps/acp/. It is critical that growers of citrus in the home garden be diligent in finding and identifying these pests as well as observing any quarantines of citrus plants and fruit that may be in place. Excellent photographs of the Asian citrus psyllid and the symptoms of huanglongbing can be found on the California Citrus Research Board website, californiacitrusthreat.org/. Even if you only have one citrus tree, it is important that you check it frequently to help stop the Asian citrus psyllid from delivering "what could be a death sentence for California citrus trees" (Citrus Research Board 2011). Be certain to plant trees from reputable, licensed California nurseries to avoid getting plants with the disease. The symptoms of huanglongbing are described in table 17.4.

Fungi that infect the trunk and roots, especially feeder roots that have critical roles in water and nutrient uptake, are important in California citrus. Because the state's climate is semiarid, oomycetes that attack citrus fruit are less important here. The distribution of citrus blast, the one bacterium that causes citrus disease in the state, is limited by climate to northern California, where there are long wet periods in winter and spring. Sanitation (removal of infected leaves and shoots) or application of a pesticide can minimize the spread of fungal diseases (see the UC IPM website, ipm.ucdavis.edu.)

Exocortis has been reduced in California because of strict regulations on budwood sources. However, scion cultivars budded to rootstocks of trifoliate orange or trifoliate orange hybrids (such as Troyer and Carrizo Citrange rootstocks) are known to express exocortis symptoms. Until very recently, tristeza was limited to old citrus-growing areas of southern California because of UC research that led to the identification of the disease and the propagation of trees for new citrus plantings made from tristeza-free budwood. However, the San Joaquin Valley is no longer free of this viral disease. Restrictions on the movement of propagating material and elimination of viruses (among other pathogens) from budwood by the Citrus Clonal Protection Program at UC Riverside are effective in controlling viral diseases as long as complimentary programs to detect and eradicate diseased trees are being conducted. Some production areas in the San Joaquin Valley no longer participate in programs to detect and eradicate diseased trees, and thus tristeza is more common there.

Different citrus diseases are caused by the same pathogen and are described according to the plant part or parts that they damage or the symptoms expressed. For example, *Phytophthora* spp. oomycetes cause a number of citrus diseases with different names, depending on the part of the tree affected—roots (Phytophthora root rot), trunk (gummosis), or fruit (brown rot) (see table 17.4). Citrus tristeza virus (CTV) causes three distinct diseases or symptomologies. In the field, sweet orange, mandarin, or grapefruit trees grown on Sour Orange rootstock can die in a matter of weeks due to CTV-induced quick decline, whereas grapefruit, pummelo, and in some cases sweet orange express stem pitting that results in reduced yields and fruit quality. In the greenhouse, CTV-inoculated lemon, sour orange, and grapefruit show distinct stunting and leaf chlorosis, a disease known as seedling yellows.

In addition to Phytophthora root rot, two other diseases commonly affect citrus roots in California: dry root rot *(Fusarium solani)* and Armillaria root rot *(Armillaria*

mellea). The first visible symptoms are usually yellowing of leaves and a slow decline of the scion. Phytophthora root rot destroys feeder roots, whereas the other two diseases also move into the wood (xylem) of the root and into the scion (see table 17.4).

Pest Control Measures

Prevention is the most economical method of controlling citrus diseases. Preventive measures can include use of tolerant rootstocks (see table 17.2) and clean budwood tested for the presence of pathogens, preplant soil preparation, good drainage, judicious irrigation management and sanitation, adequate fertilization, and control of other pests. Buy trees with a high bud union, and when planting them, maintain the same soil level as in the nursery to prevent disease problems. Staff in reputable nurseries and your local UC Cooperative Extension farm advisor will be familiar with the most important citrus diseases in your area and will know which scion-rootstock combinations are most tolerant and vigorous in your area.

Whenever possible, use mechanical control methods (remove diseased limbs, clean up debris, dislodge pests with strong blasts of water or with soap or oil sprays) and biological control methods (release natural enemies) to combat pests. Use chemical pesticides as a last resort. Chemical controls kill not only the target pests but also natural enemies, the biological enemies naturally present or introduced into the garden. Excessive reliance on pesticides may also accelerate the development of resistance to pesticides.

For the most recent control recommendations of specific citrus pests, consult the UC IPM Citrus Pest Management Guidelines, ipm.ucdavis.edu/PMG/selectnewpest.citrus.htm. For additional information on general pest management and pesticide use, see chapter 9, "Safe and Sustainable Pest Management."

Mechanical control of insect and mite pests

Mechanical methods are nonpolluting, nonpersistent pest control techniques that are effective against a number of insect and mite pests.

Strong blasts of water usually dislodge aphids. Insecticidal soaps and oil sprays recommended in the UC IPM Citrus Pest Management Guidelines are effective against a number of soft-bodied insects and mites. Use soaps and oils that are registered for use on citrus and only when your trees have been well irrigated and conditions are not windy or too hot (< 90°F).

Insecticidal soaps are effective against soft-bodied insects and mites on contact. They penetrate pest cell membranes and kill without harming trees or fruit. Apply soaps in the early morning or late afternoon.

Horticultural oils smother and kill soft-bodied insects and mites. Summer oils are available for use on evergreen trees such as citrus. Summer oils list the words *supreme, superior,* or *narrow-range* on the label. The original formulations of horticultural oils were applied to deciduous plants during the dormant season, and even though they may list application rates for use during the growing season, they are formulated differently from true summer oils. Avoid spraying horticultural oils in foggy or humid weather because the oil will dissipate so slowly that it can injure trees.

Biological control of insect and mite pests

Biological control of insect and mite pests is generally more effective in coastal regions than in the San Joaquin Valley or desert valleys. UC scientists are actively engaged in detecting and importing beneficial insects for controlling major citrus pests. A number of biological control agents that are effective against citrus pests are native to California. For many pests, however, UC entomologists have traveled to the areas of the world where citrus is believed to have originated to search for natural predators and parasites of citrus pests when indigenous parasites and predators are not available. When a particular parasitic wasp or predator looks promising, UC scientists bring it back to

California with the appropriate permits and place it into UC quarantine facilities to undergo intensive research. UC entomologists release the imported biological controls into the environment only when research results document their effectiveness and safety.

Environmental Stress and Mineral Deficiency or Excess

Environmental stresses such as nutrient deficiencies or adverse weather and soil conditions (excessive or too little irrigation water, poor soil drainage) may cause symptoms described as abiotic stress (sometimes improperly referred to as abiotic diseases). Root damage from abiotic stress can predispose citrus and other commodities to diseases caused by pathogens, and vice versa. Symptoms associated with several environmental stresses and a few comments on managing them are included in table 17.4.

Mineral deficiencies or excesses, which may be toxic, usually show up first in leaf tissue, but they eventually affect fruit size, quality, and yield. In California citrus, a few nutrient deficiencies can be problematic. The most common deficiencies are nitrogen and zinc, followed by manganese and magnesium. Iron deficiency is less common. For a description of common mineral deficiency symptoms, see table 17.4. Mineral toxicities are less common than deficiencies, but boron can cause toxic symptoms if irrigation water or soil contains excess concentrations. If you suspect boron toxicity, the irrigation water should be checked.

Foliar sprays can correct zinc, iron, and manganese deficiencies. Chelated formulations applied to the soil near the tree are also effective. A general recommendation is given above, in the section “Fertilization of Fully Bearing Citrus Trees,” but you may also consult with your local UC Cooperative Extension farm advisor about the most effective methods in your area.

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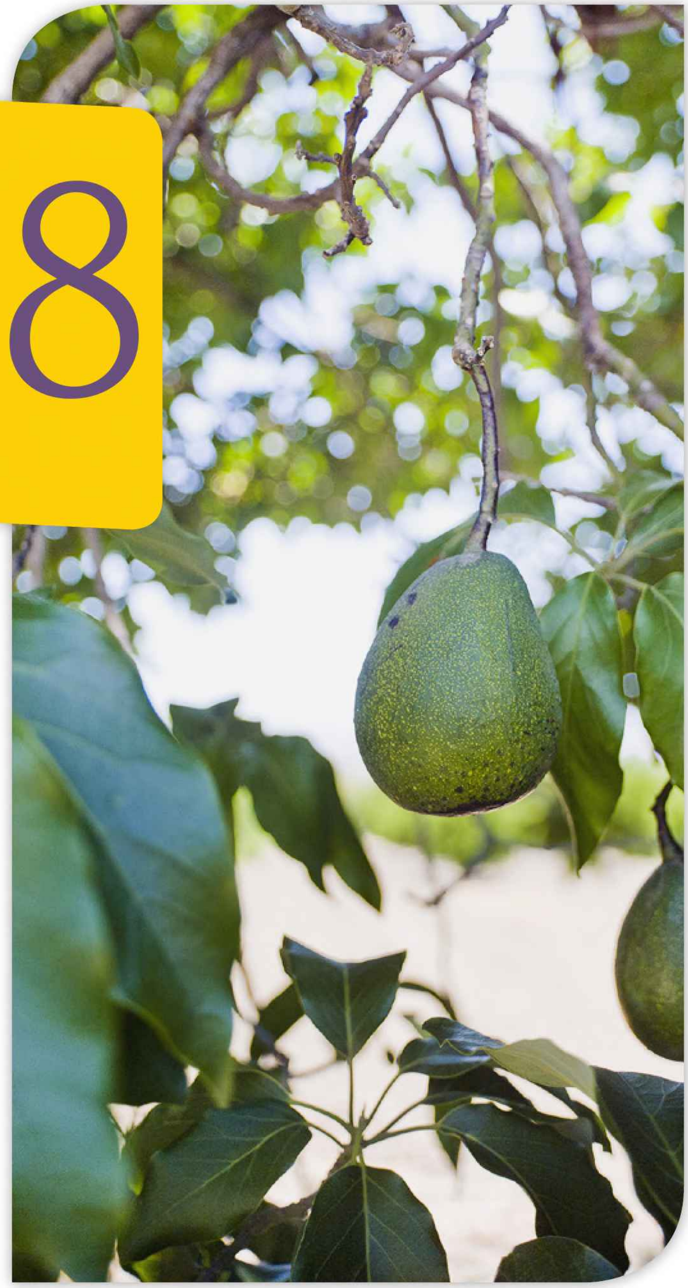
Avocados 18

Deborah Silva, Carol Lovatt,
Berthold O. Bergh, and Akif Esaklen



Learning Objectives

Understand important unique characteristics of avocado flower and fruit development.

Become familiar with avocado cultivars that do well in the home garden in various climate zones in California.

Learn the basic cultural requirements of avocado trees.

Learn some basic principles of pest and disease management of avocados.

Learn about the nutritional value of avocados.

Avocados

This chapter introduces avocados, one of California's important subtropical tree crops. Avocados are gaining in popularity nationwide. The avocado (*Persea americana* Mill.) is unique among tree fruits. It is neither sweet nor acidic, with a mild, nutty flavor. It has significant nutritional benefits due to its high (in comparison to other fruits) mineral, vitamin, and protein content and high monounsaturated fat content (oleic acid), which helps to lower "bad" cholesterol (low-density lipoprotein). In South Africa, the avocado is considered the perfect food for toddlers and young children because of its high nutritional value and digestibility. Avocados contain all essential amino acids, which means they are a fruit-based source of balanced protein nutrition, an unusual feature. Ounce per ounce, avocados are a richer source of potassium than bananas, and they have more soluble fiber than apples.

Worldwide, avocados are often eaten alone or with salt, lemon juice, or lime juice, or as part of a salad. In Mexico, you can enjoy avocado ice cream. In Brazil, the flesh of some avocado cultivars is commonly sweetened and eaten as a dessert. In many countries, the avocado is a main ingredient in shampoos, soaps, and cosmetics, including skin creams.

The flavor and texture of avocados are such that many adults encountering avocados for the first time need to acquire a taste for them. The usual progression of impressions is from varying degrees of aversion at first taste through steadily increasing acceptance to the point that avocados are prized as a distinctive delicacy. Guacamole dip, which uses mashed avocado as its base, is increasing in popularity throughout the United States. In the early 1970s, it was estimated that people in the United States averaged about one avocado per person per year. By 2012 that figure had increased more than fourfold. This chapter provides a brief introduction to the history of the avocado in California; discusses basic physiological principles of avocado tree growth and development, particularly the unique behavior of avocado flowers; describes and recommends cultivars for planting in the home garden; presents some basic information on planting, tree care, fertilization, environmental stresses, diseases, and insect pests; and highlights the nutritional value of avocados.

History and Worldwide Production

Wild avocados can be found in regions of Mexico and neighboring Central American countries, and the crop originated in this general area. Historic sites in Guatemala and Michoacan, Mexico, mark the origins of avocado use.

Mexico is the world's leading producer of avocados by volume, where they are referred to as "the butter of the poor," but in terms of monetary value, U.S. production ranks first worldwide. California is the major domestic producer of avocados. About 63,000 acres are planted with avocados in California. The more than 52,000 bearing acres produced an

avocado crop with a market value of about $460 million in 2010–2011, placing avocados among the state's top 20 crops. Florida has some commercial production, and Hawaii has a more limited crop.

In addition to the United States and Mexico, avocados are also grown in Central America, the West Indies, South America, Africa, Spain, Israel, the Philippines, Indonesia, New Zealand, and Australia. Indonesia is the world's second-largest producer of avocados, with the United States third. The United States is also the world's largest importer of avocados, approximately 331,000 U.S. tons annually. In Central America, the largest production is in El Salvador, Costa Rica, and Guatemala. In South America, Colombia is the major producer, with industries in Brazil, Chile, Peru, Ecuador, and Venezuela. In the West Indies, the Dominican Republic is the major producer, with sizable production in Haiti and Jamaica. Avocados are grown in Ethiopia, Cameroon, Zaire, and countries in southern Africa, which export much of their crop to Europe, as does the large Israeli avocado industry.

While avocados are an expensive luxury food in much of the world, they have been a staple in the diet of Central America since pre-Columbian times. In fact, the English word *avocado* is a corruption of the Spanish word *aguacate,* which dates back to the seventeenth century as a shortened version of *ahuacaquahuitl* in the language of the Aztecs. Since the time of the Spanish conquest, *aguacate* has been the common name for avocado fruit in Mexico, Central America, and the Caribbean.

Avocados are members of the aromatic laurel family (Lauraceae). *Persea*, the avocado genus, is one of about 50 genera in the family. Nearly all of the 1,000 or more laurel species are tropical, but a few are subtropical, and there are even a few temperate species, such as the classic laurel (sweet bay) of the Mediterranean area and sassafras of the eastern United States. In addition to *Persea*, the only laurel genus cultivated appreciably is *Cinnamomum,* from which commercial cinnamon and camphor are derived.

Types of Avocados and Horticultural Races

Scientists refer to avocados as having three distinct horticultural races, known as botanical varieties (as opposed to cultivated varieties), which were named for their presumed centers of origin: Mexican, Guatemalan, and West Indian. The three races are designated, respectively, as *Persea americana* var. *drymifolia*, *P. americana* var. *guatemalensis*, and *P. americana* var. *americana*. A summary comparison of the three horticultural races is provided below.

Mexican race. The leaves of this variety are anise scented. It blooms earliest in the season (fall to spring in California) and takes about 6 months from flowering to fruit maturity. The Mexican fruit are small, pear shaped, or round, and have a very thin, waxy, dark-colored skin rarely more than $^{1}/_{32}$ inch thick. Seed are relatively large to very large and often loose. Fruit pulp is commonly rich to strong in flavor, sometimes with an anise aroma, and is often fibrous. Mexican fruit have the highest oil content of the three races. They are the most cold-hardy and the most resistant to heat and low humidity but the least tolerant of soil salinity. It rarely does well in a coastal environment. The Mexican avocado is a semitropical tree that would not be expected to flower or set fruit in a tropical climate, but it is the most likely to survive winter frost. In Mexico, Mexican-race trees are reported to bear mature fruit almost continuously throughout the year at varying elevations.

Guatemalan race. The leaves of this variety do not have an anise scent. Young foliage is often reddish. Of the three races, the Guatemalan avocado blooms latest in the season, and fruit may require a year or more (up to 18 months) to achieve maturity in California but just 9 to 12

months in Florida. Fruit are small to large and more often rounded than pear shaped. Fruit skin is rough, leathery, sometimes woody, and always thick, often more than 1/4 inch. Fruit are green or black, but not as dark as the Mexican race. Seed are relatively small and almost never loose. In adaptation and tolerance to soil and climate, the Guatemalan race is intermediate between the Mexican race and the West Indian race. It is a subtropical tree and would not be expected to thrive in a tropical climate or to survive hard frost.

West Indian race. The leaves of this variety do not have an anise scent. Its foliage is pale in color. Fruit are small to large, with about 6 months from flowering to fruit maturity. Fruit skin is shiny and leathery, but seldom more than 1/16 inch thick, and it is green or reddish. The seed are relatively large and slightly loose. The pulp is mild to watery in flavor. This variety has a lower oil content than the other two races. It is the least cold-hardy of the three and the least tolerant of low humidity. The West Indian avocado is not adapted to grow anywhere in California. It is a tropical tree that would set little or no fruit in California's climate and would not be expected to survive a winter frost. It does perform well in the semitropical climate of Florida. It is the most tolerant to soil salinity, either as rootstock or scion. Despite the established name of this race, evidence now points to the Pacific coast of Central America as the place of origin of the West Indian race.

There are no known fertility barriers among the three botanical races. Hybridization occurs readily wherever trees of different races are growing in proximity, which has resulted in cultivated varieties improved by scientific plant breeding techniques. The cultivar that led California production for many years, Fuerte, is a pear-shaped natural Mexican × Guatemalan hybrid that is green at maturity. The Hass cultivar, which currently leads California production, is generally regarded as straight Guatemalan, but breeding studies at UC Riverside have indicated that Hass is perhaps one-quarter Mexican. Hass has a rounder fruit shape than Fuerte and is black at maturity. The leading cultivars in Florida are Guatemalan × West Indian hybrids, which have a different flavor from their California cousins.

Fuerte was a seed from a tree in Atlixco, Mexico, imported into California in 1911. Hass, Bacon, and Zutano were California seedlings that became three commercially successful cultivars. Their seed parents are unknown, which is typical of privately produced seedlings. Hass was one of about 300 seedlings of miscellaneous origin grown by a letter carrier, Rudolph Hass, in La Habra, California, in the late 1920s. The original Hass tree was a lucky seedling now known as the Hass Mother tree. Since the tree's fruit quality was high and it bore well, Hass patented it in 1935. Today, Hass is the leading commercial cultivar in California and worldwide.

The Remarkable Avocado Flower

Avocado Dichogamy

Avocado flower behavior is noteworthy—nothing quite like it is known in any other plant. The avocado flower has both female and male organs, which means it is structurally perfect, which is not unusual. What is unusual is that the avocado male and female organs within one flower do not function at the same time, a condition known as dichogamy, and the timing of the phases varies among cultivars. Each avocado flower is functionally unisexual. Each flower is female when it first opens. That is, its stigma will receive pollen from other avocado flowers, but its stamens do not shed pollen at this first opening.

The female-stage avocado flower has a receptive stigma but also nonfunctional male parts (fig. 18.1). The female stage flower opens first, but for only 2 or 3

hours. The flower then closes and remains closed the rest of the day and that night. The following day, the flower opens again. But now the stigma will ordinarily no longer receive pollen. Instead, the flower sheds pollen and is known as a male-stage flower. After remaining open for several hours on the second day, the male-stage flower closes again, this time permanently. Thus, each avocado flower is female at its first opening and male at its second opening.

In California, honey bees transfer pollen from male-stage flowers to stigmas of female-stage flowers. Once pollen has been successfully transferred to the stigmas (pollination), the pollen germinates, producing a pollen tube that advances through the style and ovary tissues to the ovule, which contains the egg (fig. 18.2). Depending on the temperature, the pollen tube requires only about 2 to 4 hours to reach the ovule. Once the pollen tube delivers the sperm to the egg inside the ovule, the sperm and egg must fuse (fertilization), which results in formation of the embryo. Fertilization initiates the development of the ovary into a mature avocado fruit and the ovule into the seed, inside of which is the embryo. This embryo can then develop into the young seedling avocado tree of the next generation. The seed provides plant growth regulators necessary for fruit set and fruit development.

Figure 18.1

Schematic view of the avocado flower. *Source:* After Bergh 1975.

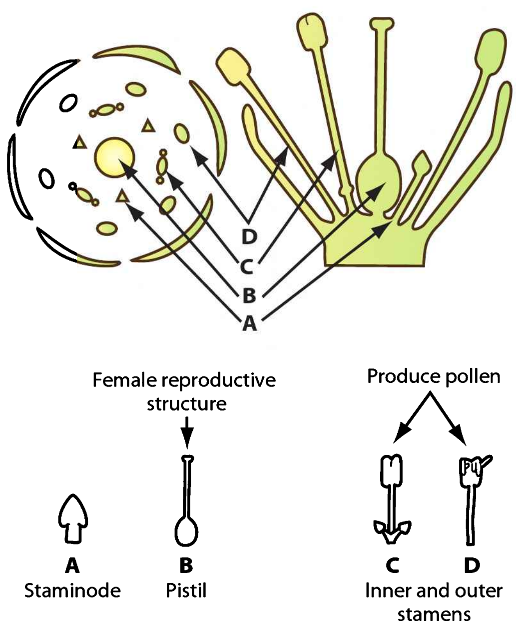
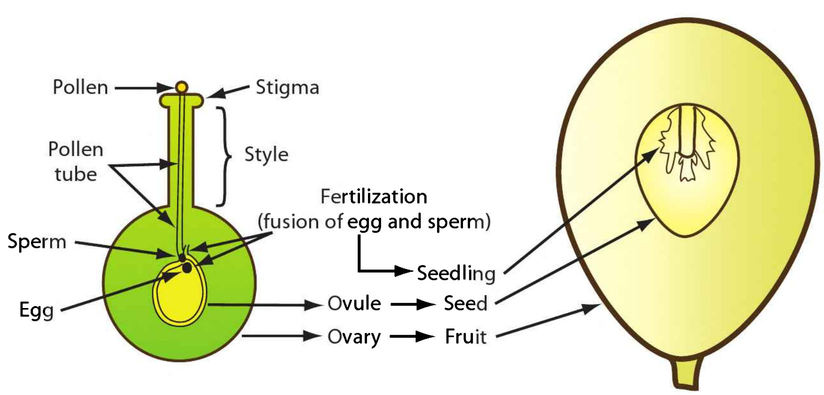


Figure 18.2

Avocado pollination and fertilization. *Source:* After Lovatt 1990.



The Two Types of Flowers in Avocado Cultivars

Nature has provided for avocado cross-pollination by creating two types of botanical cultivars known as A and B, based on their flower behavior. The A flower is functionally female in the morning of the first day and functionally male in the afternoon of the second day, if the weather is warm. The B flower is functionally female in the afternoon of the first day and functionally male in the morning of the second day, as shown below.

	First day		Second day	
Type	Morning	Afternoon	Morning	Afternoon
A	female			male
B		female	male	

Since different flowers open on different days, the two types of avocado cultivars complement each other with their diurnal synchrony. Both are functionally female on their first day and functionally male on their second day, but they differ in the

time of day that they are male and female. A cultivar of one type provides pollen (functionally male) when a cultivar of the other type is receptive (functionally female). Therefore, the pollination and fertilization necessary for fruit set can occur.

On trees of an A cultivar, flowers open for the first time in early or midmorning, remain open with the stigma receptive to pollen until about noon, then close and remain closed until about noon of the second day, when they reopen and begin shedding pollen with the stigma no longer receptive. Finally, the flowers close permanently that night. On a single tree, thousands of flowers may open for the first time the same morning, then follow the same behavior pattern synchronously hour after hour for their 2-day existence. The total opening cycle on an A tree spans about 36 hours. Flowers on trees of a B cultivar function analogously but with transposed timing. The opening cycle on a B tree spans about 24 hours. The difference in cycle time reflects the relative length of the closed period between openings.

A sampling of commercial cultivars classified as A or B include the following:

A cultivars: Hass, Gwen, Pinkerton, Reed, Anaheim, Lamb Hass

B cultivars: Fuerte, Zutano, Bacon, Whitsell, SirPrize

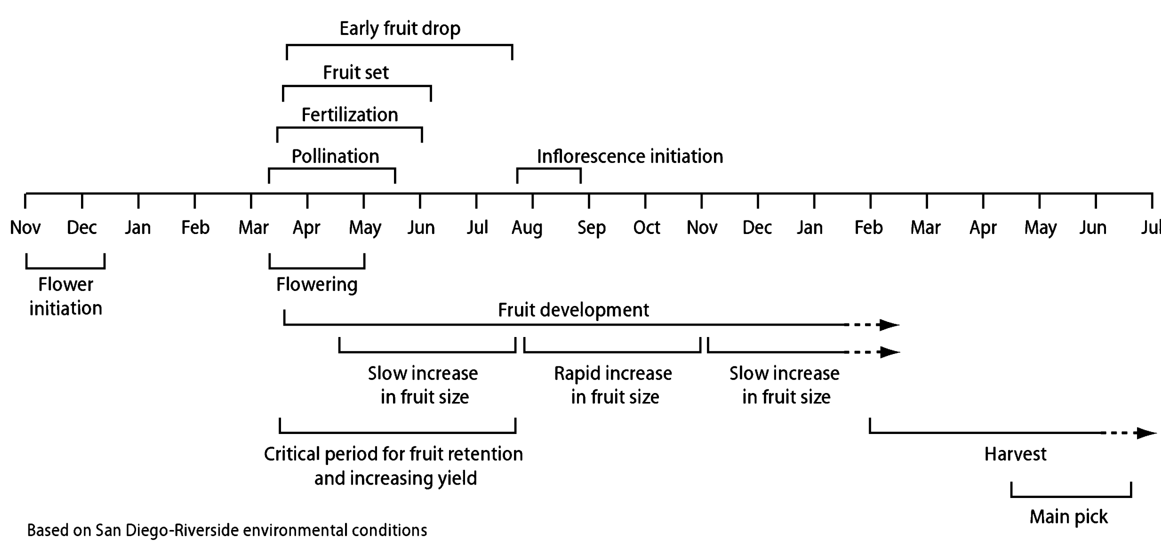
Under typical California weather conditions, which are subtropical, both the A and B cultivars bloom continuously for about 2 months, and it is rare for the earliest cultivar to finish blooming before the latest begins. Whereas summer flush vegetative shoots of the Hass avocado in California transition to reproductive shoots and initiate inflorescences sometime from the end of July through August, individual avocado flowers are initiated about 2 to 3 months before the tree is in full bloom. The seasonal cycles of flowering, fruit set, and fruit development for the Hass avocado in San Diego–Riverside environmental conditions are shown in figure 18.3.

Pollination and Cross-Pollination

Flowering in A and B cultivars behaves with clocklike exactness only when the average temperature (night minimum and day maximum) is above about 70°F. As the temperature falls, the daily openings for the functionally male and female flowers become delayed and irregular such that a single tree may have flowers in both the female and male stages at the same time,

Figure 18.3

Flowering, fruit set, and fruit development of the Haas avocado in California. *Source:* After Lovatt 1999.



which explains how large blocks of just one cultivar set heavy crops via self-pollination. With colder temperatures, the male opening may be delayed 1 or more days, and other abnormalities in flower behavior may occur. Either opening may continue through the night and into the next day. Below about 60°F, however, there may be no fruit set.

Research at UC Riverside (Garner et al. 2008) has shown a weak positive correlation between cross-pollination and yield in some Hass avocado orchards, but the data suggested that self-fertilization was responsible for a substantial portion of fruit set in California groves. However, in earlier studies, when an A and a B cultivar grew with their branches overlapping or at least close together, fruit set increased by 40 to 150%. Many commercial growers plant B cultivars to provide a complimentary source of pollen for the Hass avocado, an A cultivar, and place beehives in their orchards. Since home gardeners are not concerned about yield and profit, they do not need to make provision for cross-pollination. Nevertheless, it is useful to understand the factors that can influence and increase fruit set, if desired.

Figure 18.4

Floral shoots of a Hass avocado are either determinate or indeterminate.

Shoot Growth and Bearing

Avocados produce two types of floral shoots: determinate floral shoots, in which the apical bud is a flower, and indeterminate floral shoots, in which the apical bud remains vegetative and produces a vegetative shoot. Determinate floral shoots occur along the branch, and indeterminate floral shoots are formed at the end of a branch (fig. 18.4). The Hass avocado has approximately 150 flowers per inflorescence.

Hass avocado trees in California produce approximately 90% indeterminate floral shoots. This type of floral shoot sets less fruit than a determinate floral shoot. However, fruit set should not be a concern since a single tree will likely produce a million flowers during a single spring bloom period. Despite the fact that less than 0.1% of this total results in fruit that hold to maturity, good yields are obtained. A yield of 200 8-ounce fruit, or about 100 pounds per tree, results from approximately 0.02% fruit set.

Avocado trees have a strong tendency to be alternate, or biennial, bearing, alternating moderate to heavy crops one year with light crops the next year. This condition can be initiated by climatic or cultural conditions that result in excessive fruit drop and poor yield or by optimal conditions for fruit set that result in a bumper crop. Spring flush vegetative shoots that set fruit produce few inflorescences the following spring. In addition, spring shoots that set fruit produce very little summer and/or fall vegetative shoots that would also contribute inflorescences at bloom the following year. Thus, when trees are carrying a heavy crop, the number of shoots that can produce inflorescences the next spring, that is, those that did not set fruit, is significantly reduced. Thus, reduced flower number is the cause of the low yield that occurs in the year following the heavy crop.

Avocado Trees

Like many tree fruits, avocado trees sold today are not grown on their own roots. Avocado trees at a retail nursery consist of a scion-rootstock combination, in which the rootstock provides the lower few inches of the trunk and the tree's roots, and the scion includes the major portion of the trunk, all branches, leaves, and fruit (fig. 18.5). Thus, it is desirable to bud or graft scions of high-yielding cultivars with good-quality fruit (see table 18.1) to rootstocks preferably with superior disease tolerance.

Fruit-Bearing Scions

Unlike citrus, the avocado produces only sexual seed, never seed of nucellar origin that are clones of the mother. In addition, the dichogamy of avocados largely ensures cross-pollination. Consequently, seedlings that grow from the seed within the fruit produced by a single tree (or cultivar) are extremely variable, providing an abundance of genetic variability among their offspring from which to select for trees with

- cold hardiness
- good fruit set (high yield)
- consistent and early production
- high-quality fruit that have superior, rich flavor and a long storage life on the tree and postharvest
- fruit that weigh about 10 ounces (not too small or too large), with a relatively small seed and a uniform shape and size
- skin that peels easily, is thick enough to protect the flesh in transit to markets but not thick enough to add unnecessary waste material or prevent the consumer from determining ripeness by gentle palm pressure
- acceptable fruit color when ripe

The desired fruit color depends on consumers' past experiences and expectations. Today, a dark skin color is preferred in most domestic markets, where Hass has become the standard. Color is unimportant in a few markets, and green is preferred where Fuerte has been established as the standard of quality.

Three Avocado Fruiting Cultivars Selected and Patented by the University of California

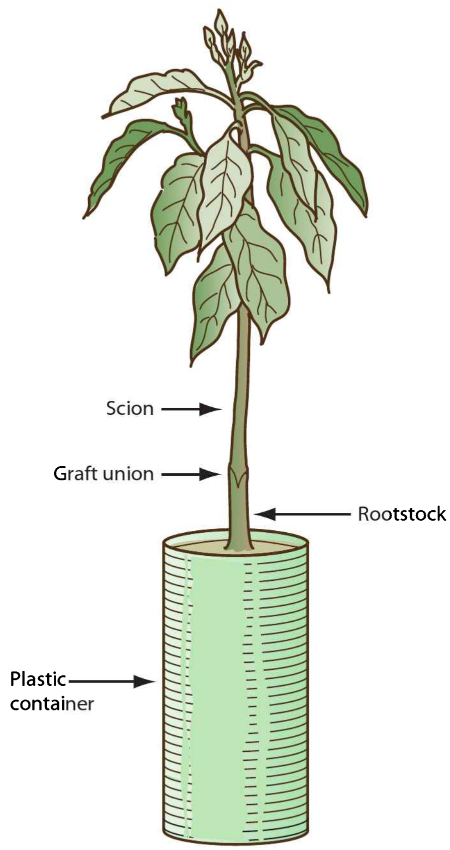
Gwen. Gwen fruit, compared with the Hass standard, remain green skinned when ripe, are a little rounder, have similarly superior flavor, and retain their superior flavor later in the season, but they may shrivel when picked at the beginning of the Hass harvest season. Gwen is more precocious, and, under favorable conditions (which in some cases appears to involve a nearby cross-pollinator), Gwen can produce twice as much fruit as Hass per acre on semidwarf trees with lower picking costs and easier spraying, if needed. These features reduce production costs per pound and increase competitiveness and profitability for commercial growers. Gwen's commercial expansion in California has been limited by its green-skinned fruit in a market where Hass dominance has made a black-skinned fruit highly preferred, by mediocre production in some locations, and by its susceptibility to persea mite. For backyard purposes, however, skin color is usually unimportant, and the smaller, narrower Gwen tree has several advantages.

Lamb Hass. Lamb Hass apparently matches Gwen's high productivity on a somewhat more vigorous tree with a fruit that ripens black but later than Hass, with eating quality a little below the Hass and Gwen ideal.

SirPrize. SirPrize is a high-quality, early-season black fruit (earlier than Hass) on a tree that does not usually grow as tall as the Bacon or Zutano early-season standards. It has a tendency to not be especially prolific in setting fruit. Its B flower is promising as a pollinator for major A cultivars.

Figure 18.5

Typical container-grown nursery avocado tree showing scion grafted to rootstock.



Avocado Rootstocks

The most sought-after rootstock characteristic is resistance to *Phytophthora cinnamomi*, a soilborne, fungus-like organism that causes root rot, the most serious avocado disease in California and other avocado-producing regions of the world. Other soilborne pathogens to which rootstock resistance has been sought are collar rot, caused by *Phytophthora citricola*; wilt, caused by *Verticillium albo-atrum*; and branch canker and stem-end rot, most recently determined to be caused by species of *Botryosphaeria*, with *Neofusicoccum luteum* and *N. australe* the predominant species, according to recent research by Akif Eskalen and his team at UC Riverside. Avocado rootstocks are not known to have significant effects on fruit quality, although they do affect tree vigor and productivity. Fuerte and Hass scions grow up to twice as rapidly on Guatemalan rootstocks than on Mexican rootstocks, and fruit set is proportional to tree size.

George A. Zentmyer, plant pathologist emeritus at UC Riverside and member of the National Academy of Sciences, searched widely in California and throughout Mexico and Central America for sources of resistance to *Phytophthora cinnamomi*. Of his several tested rootstock selections, Duke 7 performed best and has considerable commercial usage in California and other avocado-growing countries. In avocados, asexual propagation of rootstocks is used to produce clonal rootstocks. Clonal rootstocks are preferred over seedling rootstocks because root rot–resistant traits of the parent tree from which the clone derives are preserved; whereas, in a seedling rootstock, the parent's root rot–resistant traits are usually lost due to cross-pollination and reorganization of genes. Until about 1977, practically all of California's commercial avocado trees grew on sexually produced seedling rootstocks; only the scions (fruiting tops, such as Hass or Fuerte) were asexually produced (cloned).

The original method for producing clonal avocado rootstocks was invented at UCLA by E. F. (Ted) Frolich and was adapted to commercial avocado rootstock production by Brokaw Nursery, Inc., in Saticoy, California. To create a clonally propagated rootstock with the root rot–resistant traits of the parent avocado tree using the Brokaw clonal rootstock method, the nursery grafts budwood from a rootstock tree with proven root rot resistance to a nurse seedling. Shortly after budding, a constriction ring is placed around the stem of the nurse seedling. The young rootstock is allowed to grow for a few weeks, then is placed in the dark in order to form elongated growth with softened bark (etiolation). After 4 to 6 weeks in the dark, the etiolated rootstock shoot still on the nurse seedling is placed back on the greenhouse bench, and potting soil with rooting hormone is placed around the

graft union of the rootstock to the nurse seedling. As the young rootstock grows and forms roots, the nurse seedling is gradually killed by the constriction ring. After several months, the rootstock has its own roots and is now the free-living clonal rootstock. A bud of the desired fruit-bearing cultivar that serves as the scion, such as Hass or Gwen, is then grafted to the clonal rootstock.

In the early 1980s, the University of California was recommending the clonal rootstock Duke 7 as the rootstock of choice because of its superior resistance to root rot. Today, several rootstocks perform better than Duke 7, such as Toro Canyon, Dusa, and Latas. The home gardener can special order a scion cultivar of choice on one of these Phytophthora-tolerant clonal rootstocks from a retail nursery.

Avocado Cultivars for Planting in the Home Garden

The climate zone determines which avocado cultivars perform best, when fruit are harvested, and what pest and disease problems are more common. Table 18.1, although not exhaustive, describes the major attributes of 14 avocado cultivars available to the home grower. Particular climatic requirements and home-growing conditions are noted in table 18.1 and in the section "California Climate Zones for Growing Avocados," below.

Several of the cultivars listed in table 18.1 are not recommended for commercial growers because their productivity or quality is less than Hass, the current industry standard. Two of the older commercial cultivars, Bacon and Zutano, are listed in table 18.1 because they are widely grown. Neither cultivar is recommended for the home grower because both grow quite tall, which makes harvesting difficult, and because newer cultivars are good replacements with higher-quality fruit. Harvesting periods given in table 18.1 are approximate and broad. The timing of maturation of the fruit of a particular cultivar may vary slightly from year to year, and microclimates in the home orchard affect time to maturity as well; thus, the periods given in table 18.1 should not be interpreted as absolutely precise.

California Climate Zones for Growing Avocados

In California, avocados grow where temperatures do not fall much below freezing—usually in areas with coastal climates or in thermal belts surrounding some of the interior valleys. Avocado trees grow well under a variety of conditions, but good fruit production depends on favorable weather, especially during bloom. Chilling breezes may reduce or cause complete failure of fruit set for some cultivars, and sudden hot spells often cause young fruit to drop. In general, the two major dangers for avocado trees growing in California are freezing injury, especially for the tender, higher-quality cultivars, and above-freezing chilling injury, which prevents proper tree growth and independently limits fruit set on healthy trees. Hard Santa Ana winds in fall and winter blow leaves and fruit off the tree and can break brittle avocado limbs. The risk from wind varies from year to year and from region to region, but it is appreciable from Oxnard south.

Figure 18.6 depicts eight climate zones where avocados can be grown in California. This diagrammatic scheme is based on proven commercial success, but a backyard grower can certainly produce avocado fruit in much more of California than the zones depicted in figure 18.6. In the markedly colder areas of the state, backyard growers will be limited to the cold-hardy, short-season cultivars, such as Duke or Mexicola, with Jim, Stewart, and SirPrize worth trying, as noted in table 18.1. It should also be taken into account that zones 3 and 4 include quite diverse climates with very different avocado possibilities. Home gardeners are encouraged to consult the most recent edition of the

Table 18.1.

RECOMMENDED AVOCADO CULTIVARS FOR PLANTING IN THE HOME GARDEN

Cultivar	Comments	Parentage*	Fruit skin			Fruit quality	Fruit flavor	Seed size	Bearing habit†	Flower type	Cold limit‡	Mature season§
			Ripe color	Texture	Thickness							
Bacon	Upright tree growth can make harvesting difficult. Peel deteriorates if fruit left on tree too long.											
		Mexican	green	smooth	thin	good	sweet, mild	large	consistent	B	24°F	Nov–Mar
Duke	Not a commercial cultivar due to short season, loose seed, skin too thin for shipping. Valuable to the backyard grower for its agreeable flavor, good fruit size, wind and heat tolerance, and especially its maximum cold tolerance. Mostly used as rootstock.											
		Mexican	green	smooth	very thin	good	spicy	large	consistent	A	20°F	Sep–Oct
Fuerte	Fuerte blooms Feb–Apr. Was California's leading commercial cultivar due to its excellent fruit, long season, and some cold hardiness. Now largely replaced by the better-bearing Hass but may be worth a try where there is plenty of space for this very large tree.											
		Guatemalan × Mexican	green	leathery	thin	excellent	mild	medium	alternate	B	27°F	Nov–Mar
GEM	Seedling of Gwen selected by UCR researcher Gray Edward Martin. Fruit are produced on a semicompact, vase-shaped tree. The teardrop-shaped fruit are borne in clusters, typically in the interior of the tree protected from sunburn; the peel turns from green (when on the tree) to a dark burgundy/black when ready to eat.											
		Guatemalan	black	somewhat pebbly	thick	excellent	nutty	medium	somewhat alternating	B	27°F	Nov–Mar
Gwen	Patented in 1984 by UC Riverside. Small, upright tree takes little backyard space and usually bears early and heavily. Not productive everywhere. May need a pollinator. Very susceptible to persea mite. Very susceptible to wind, heat, cold, and dryness. Commercial season is delayed until April because of skin shriveling when ripened earlier.											
		mostly Guatemalan	green	small pebbly	medium	excellent	rich nutty	medium	fairly consistent	A	30°F	Apr–late summer
Hass	Most common commercial cultivar. Comprises more than 80% of California acreage. Wide adaptability, except in cold, interior regions. High quality and long season appeal to backyard growers, if enough space is available for a large tree. Where summers are not too hot, fruit that stay on tree beyond July may develop undesirably strong flavor late in season. Susceptible to persea mite.											
		mostly Guatemalan	black	pebbly	medium	excellent	rich nutty	small-medium	alternate	A	30°F	Jan–Jul or year-round
Jim	Green, thin-skinned avocados are fading commercially. Jim has advantages over the two old-time standards Bacon and Zutano. Jim has a longer season and better fruit quality than Zutano, better fruit set (in some places) than Bacon, and shorter trees than either of them. Jim may be useful where considerable cold hardiness or a B-type flower pollinator is needed.											
		mostly Mexican	green	smooth	thin	very good	mild spicy	medium	fairly consistent	B	24°F	Nov–Feb
Lamb Hass	Patented in 1996 by UC Riverside. Production higher than Hass on smaller, compact trees. Has done well but additional testing is needed. Superior to Hass in tolerance to wind, heat, and persea mite. Consumer taste tests rate fruit highly, but to connoisseurs, it is below Hass or Gwen excellence. Its cold hardiness is unknown, but better than 30°F is not expected.											
		mostly Guatemalan	black	pebbly	medium	very good	fairly rich	medium	somewhat alternating	A	unknown (estimated at 30°F)	May–Nov

Table 18.1. cont.

RECOMMENDED AVOCADO CULTIVARS FOR PLANTING IN THE HOME GARDEN

Cultivar	Comments	Parentage*	Fruit skin: Ripe color	Fruit skin: Texture	Fruit skin: Thickness	Fruit quality	Fruit flavor	Seed size	Bearing habit†	Flower type	Cold limit‡	Mature season§
Mexicola	Extremely cold-hardy like Duke but noncommercial because of thin skin, short season, too small a fruit. Mexicola's flavor preferred by some over that of the best commercial Guatemalans, such as Hass.											
		Mexican	purple	very smooth	very thin	good	anise-like	large	consistent	A	20°F	Aug–Sep
Pinkerton	With cross-pollination (and sometimes without it), Pinkerton is a producer of superior fruit. Where the ocean moderates summer heat, fruit can hang on the tree well past April without flavor deterioration, as in Hass. Wide adaptation, but not northerly (zones 4 and 8, fig. 18.6). Low persea mite tolerance. Its often large fruit become quite necked inland. The smallest seed of California commercial cultivars.											
		mostly Guatemalan	green	pebbly	medium	excellent	rich	small	usually consistent	A	30°F	Dec–Apr
Reed	A heavy producer of round fruit that become larger than commercially desirable. Large size encourages early picking, but in May flavor is usually bland. Rich flavor develops considerably later in its long season. Dubious for zones 3, 4, 7, and 8 (fig. 18.6). Moderately tolerant to persea mites.											
		Guatemalan	green	fairly smooth	thick	excellent	rich	medium	very consistent	A	30°F	May–Nov
SirPrize	Patented in 1996 by UC Riverside. Fruit are like large, black, rough Fuerte. Earlier than Hass. Better eating quality and longer season than other early maturers, except the alternate-bearing Fuerte. Both traits are desirable for home gardeners. Black skin is commercially advantageous. Mature fruit easily identifiable. Tends to be a light producer. Young fruit have distinct ridge. So far, moderate tolerance to wind and persea mites. Cold hardiness is hoped for. Needs additional testing.											
		Mexican × Guatemalan	black	leathery	thin	excellent	nutty rich	small	somewhat alternating	B		Nov–Mar
Stewart	Of the cultivars suited to colder regions, only Stewart receives top rating for total fruit quality: medium size, very attractive appearance, small seed for its season, flesh neither nutty nor spicy, yet delicious, and superior peeling in spite of thin skin. Production is good in some locations and inferior in others.											
		mostly Mexican	purple	leathery	thin	excellent	flavorful	medium	variable	A	25°F	Oct–Dec
Wurtz	Small tree (8–10 ft) ideal for small gardens or large containers. May also be sold as Dwarf, Littlecado, or Minicado. Only real virtue is unique, weeping-umbrella short tree.											
		Guatemalan	green	pebbly	medium	good	mild	large	alternating	A	31°F	May–Aug
Zutano	Upright tree growth can make harvesting difficult. Mediocre flavor. Pear-shaped fruit. Newer cultivars are better.											
		Mexican	green	smooth	thin	mediocre	watery	large	consistent	B	24°F	Oct–Feb

Source: Adapted from Bender 1996; information based in large part on observations by Bob Glein and Gray Martin.

Notes:

*Guatemalan or Mexican, the two avocado races adapted to California.

†The majority of avocado trees are alternate bearing, meaning that they bear a heavy crop one year and a sparse crop the next (Lovatt 2010); however, there are varietal differences. For the home gardener with only one tree giving fruit in a given season, alternation is undesirable. All cultivars listed in this table bear fruit in approximately 3 years.

‡The approximate tolerance of established trees 3 years or older to cold temperatures. Tolerance varies with crop size, degree of hardening off before the freeze, any cultural weaknesses, length of time at that temperature, and other factors.

§Mature season can vary with factors affecting time of bloom and with seasonal weather, especially mean temperature. Usually the earlier the maturation, the shorter the time until the fruit drops or breaks down, but this depends partly on mean temperature also. Flavor improves as fruit remains on the tree after it has reached palatable maturity; however, eventually, as noted for Hass, flavor may deteriorate.

Figure 18.6

Eight climate zones for growing avocados in California. *Source:* California Avocado Society.

Sunset Western Garden Book (Brenzel 2012) for much more detailed climatic zoning and useful climate analysis. In the discussion below of important climate zone attributes, reference is made to both figure 18.6 and to Sunset zones. Two additional valuable sources of information are local UC Cooperative Extension farm advisors in your county who have expertise in subtropical horticulture and your own observations of avocado trees already growing in the area of interest.

Southern California Coast (Zones 1 and 2 in figure 18.6; Sunset Zone 24)

This coastal region extends from the Mexican border through San Diego, Orange, Los Angeles, and Ventura Counties to about Point Conception, west of the city of Santa Barbara. This coastal strip varies from a few yards to a few miles wide, depending on the location of cliffs or hills that obstruct ocean airflow. Note that Sunset treats this region as one climate zone (24); whereas, commercial avocado interests consider that it has separate southern and northern sections. There is little climatic difference of significance between these two sections, the chief variability being the winter cold from the mouths of canyons at certain points in both sections. The influence of the Pacific Ocean in this coastal zone means that some places here have not recorded a frost for decades, and nearly all of this region is considered functionally frost-free. In this zone, climatic limitations for growing avocados derive from chilling injury. Avocado trees exposed directly to constant, cool, on-shore summer breezes may be so stunted that they never bloom; therefore, some natural or artificial barrier is needed. Most Mexican-race cultivars are expected to have inferior yields in this zone, and among Guatemalans, B cultivars may also yield poorly, which is believed to be related to chilling at bloom time. Soil immediately adjacent to the Pacific Ocean may be high in salinity due to spray and mist. Saline soil is inappropriate for avocado production.

Central California Coast (Zones 3 and 4 in figure 18.6; Sunset Zones 17 [portion] and 16)

Here, the southern and northern zones are indeed distinct climate zones. The southern zone of the Central California Coast is comprised of the coastal strip north of zone 2 in figure 18.6 to the town of San Simeon. This region averages cooler temperatures than the Southern California Coast; thus, the chilling danger is greater and limits suitable avocado growing sites. The northern zone of the Central California Coast along the Monterey Bay shares with southern Spain the distinction of being the world's most northerly commercial avocado region. However, the portion of Sunset zone 17 extending northward from San Simeon is too cold for avocado production; slightly more inland, zone 16 is sufficiently warmer, with low frost risk, and avocados are commercially successful

in limited inland places around the Monterey Bay.

Southern California Transitional (Zones 5 and 6 in figure 18.6; Sunset Zones 21 and 23)

These are much broader regions, inland from and adjoining the Southern California Coast region. The southern zone (5) is especially large, including the Escondido-Fallbrook avocado heartland and a wide northwest sweep past Los Angeles. Note that figure 18.6 may be misleading in suggesting that the entire area enclosed is commercial avocado country. As shown in the *Sunset Western Garden Book*, some regions here are colder in winter than others. But the areas defined in *Sunset* as zones 21 and 23 can probably successfully grow any of the avocado cultivars listed in table 18.1. Preference would ordinarily be for the longer-season, higher-quality cultivars adapted to this relatively mild climate. The northern zone of this Southern California Transitional region (zone 6) has a smaller but also very favorable region for avocados, including the Santa Paula–Fillmore Valley and extending southwest past Moorpark, Somis, and Camarillo to the northern tip of the Southern California Coast. Again, some parts of zone 6 are too cold for growing choice avocados without suffering freeze damage in some years.

Southern California Interior (Zone 7 in figure 18.6; Sunset Zones 18 and 19)

This region generally includes Riverside, San Bernardino, and Hemet, which are hotter and drier in summer and colder in winter than the Southern California Coast region. A number of cautionary comments are essential. In this region, figure 18.6 could be misleading in that a large part of zone 7 in figure 18.6 is the colder zone 18 in *Sunset.* Both zones 18 and 19, as defined in *Sunset,* are irregularly intermixed. The Inland Empire cities of Riverside, Hemet, Perris, and Elsinore are actually in *Sunset* zone 18. That is, the cities are centered in valley bottoms where cold air settles, draining away from the hillsides that are therefore warmer and identified in zone 19. But temperature varies inversely with altitude, so higher elevations become progressively colder again. Any barrier that impedes air movement may increase frost damage by trapping cold air in the slope above it and reducing air drainage below it. Conversely, by choosing close proximity to the south side of a tall wall or even dense trees, the backyard avocado grower may trap enough heat to make a crucial difference. Frost risk increases a bit with each step from Sunset zones 24 to 23 and from zones 21 to 19, but the cultivars in table 18.1 that are most frost-sensitive, as well as highest in fruit quality, are well worth trying here also, especially in favored locations.

The progression from Sunset zone 24 to 23 and from zone 21 to 19 is a progression of increasing summer heat and dryness. Avocados thrive on heat, but the lower humidity means increased irrigation needs. Note that zone 19 extends irregularly from zone 7 in figure 18.6 south to the Mexican border and west to San Fernando and Chatsworth.

San Joaquin Valley Interior (Zone 8 in figure 18.6; Sunset Zone 9)

This region includes a narrow strip of the San Joaquin Valley from northern Kern through Tulare and Fresno Counties. It gets more winter rain than zone 7, which is beneficial not only in reducing water costs but also in better leaching of soil salts, to which the avocado is especially sensitive. Like Sunset zone 19, zone 9 is favorable for commercial avocados because it is elevated above neighboring land for good cold air drainage. But it is much farther north and inland; the more rigorous climate rules out the industry standard Hass cultivar in spite of its exceptionally wide adaptability. Of the standard, hardy cultivars, Bacon bears poorly in this region. There is interest in testing the new SirPrize in this region.

Influence of Microclimate on Backyard Avocado Growing

This general discussion of climate, particularly in the southern California interior, points to the great importance of local microclimates to any avocado grower. These microclimates are quite obscured by the broad outlines in figure 18.6 and even by the much greater detail of the *Sunset Western Garden Book*. The microclimate issue is of special significance to the backyard grower in choosing tree location. The Sunset zoning can lead to the misconception of too great precision: not only do the zones shade imperceptibly into each other, but the approximate boundary line can shift back and forth many miles with unusual weather conditions. Finally, the grower must be prepared, at least mentally, for erratically occurring severe freezes that cause devastation, even into parts of the Southern California Coast (Sunset zone 24). The backyard grower is, of course, not limited to the cultivars and regions that constrain the commercial farmer selling for profit. Avocados can be produced successfully in many other parts of California if one is willing to settle for the shorter picking season of the hardier avocado cultivars (see table 18.1).

In California, Mexican-race trees usually do better inland, whereas Guatemalan types generally do better in the coastal avocado-growing areas. Hass has an exceptionally wide adaptability, except for cold sensitivity. But even in the best Hass locations, Lamb Hass may be superior. The most cold-hardy cultivars (noted in table 18.1), Duke, Mexicola, and to a lesser degree, Jim and Stewart, are recommended not only for frostier locations but also for other adverse climate conditions such as high heat, wind, and other stresses. Fuerte bears well only in very limited locations.

Through its Variety Committee, the California Avocado Society, californiaavocadosociety.org, has given excellent guidance on choosing commercial cultivars for specific climate zones. The home gardener can use this information as a starting point, while recognizing that he or she has a much wider choice because profitability and keeping a business afloat are not primary factors in the decision-making process.

Fruit Maturity

Unlike many fruits, avocados are not edible on the tree. That is, maturity is not synonymous with ripeness. Only after its stem is severed will an avocado fruit begin ripening—the ethylene-mediated physiological process that induces softening of internal fruit tissues so that the fruit can be eaten. The fact that avocados do not ripen on the tree is a major advantage. Because the fruit of the better avocado cultivars can be stored on the tree for months after reaching palatable maturity, the backyard grower can pick a few when ripe fruit are needed a few days later.

Cultivars vary widely in their time of achieving maturity and length of tree storage before fruit drop or deteriorate. Table 18.1 gives approximate months of fruit maturity for the zone 5 (see fig. 18.6) commercial heartland. At least four factors influence time of maturation:

Elevation: maturity is delayed about 1 month for each increase of 325 yards.

Latitude: maturity is steadily delayed as one moves northward.

Local temperature differences: air currents and sun exposure affect maturity.

Location: southwest-facing slopes can speed up maturity due to increased light and heat.

All four factors reflect the correlation between temperature and a plant's internal physiological activity. For any climate zone, weather will vary from year to year; differences especially in mean temperature can advance or retard maturation of avocado fruit by a couple of weeks or more and can have an even more pronounced effect on the length of time fruit can be stored on the tree. Thus, predicting precise timing of fruit

maturity is as complicated as predicting the weather.

Usually, the quicker a cultivar matures fruit, the shorter its season. Hence, Mexican-race cultivars have a much shorter season than Guatemalans. But cultivars do differ. The Fuerte and the new SirPrize have remarkably long picking seasons, considering their early maturity. The Hass and Gwen have such good on-tree storage that, from a single tree, edible (if not very palatable) fruit can be picked year-round. Maturity variability on a given tree often results from differing time of fruit set. For example, the Pinkerton cultivar blooms over a very long period. A few early-set, nearly round fruit can mature a month or two before the much glossier and slimmer late-set fruit, with the end of the season differing accordingly.

Palatability usually increases with time past minimum maturity, but late in maturity, the flesh may begin to taste rancid upon ripening and the seed inside an avocado fruit may germinate, and the root of the new plant can grow into the flesh of the fruit and out through the skin.

Selecting and Buying Avocado Trees

Producing a clonal avocado rootstock requires special facilities and expertise; thus, it is more practical for home gardeners to buy from a reliable retail nursery professionally produced trees consisting of a rootstock grafted with the desired fruiting cultivar (see table 18.1). The numerous retail nurseries throughout the state are supplied by a few wholesale nurseries that specialize in grafting avocado trees. Most retail avocados are on ordinary seedling rootstocks (not clonal rootstock), but the knowledgeable home gardener can have his or her local retail nursery order a special clonal-rootstock tree, recognizing that the cost will be considerably higher. In addition, because most of the fruiting cultivars in table 18.1 are noncommercial cultivars, obtaining the desired fruiting cultivar may require a special order, even if the scion is not grafted onto a clonal rootstock.

Before making a purchase, check with the nursery to verify that the fruiting cultivar will produce well in your climate zone and in the microclimate in your home garden or orchard. Decide on the number of trees you will need and order them well in advance of your intended planting date. It takes time to propagate avocado trees, and the nursery may need 9 to 12 months' advance notice to meet your planting date, depending on the quantity you intend to purchase and especially on the cultivar you choose.

Inspect a tree before purchasing it. Make sure that the bud union (the point where the scion and rootstock join) is smooth and well healed. Avoid trees that have weak or ragged bud unions. Do not accept stunted trees or trees with off-type foliage, off-colored or sparse foliage, or a wilted appearance, because these may be signs of disease such as avocado root rot. The likelihood of buying diseased trees from a reputable retail nursery is slim, but if a tree lacks vigor and has some of the visible symptoms described above, reject it. Even at a reduced price, a bargain tree may be no bargain.

Two types of avocado trees are available to the home gardener: field grown and greenhouse grown. Field-grown trees are grown outdoors in nursery rows or in plastic containers. They may be standard budded or tip grafted. Some nurseries prefer to use a combination method, growing the seedlings and grafting in the greenhouse, then moving the young, grafted seedlings outside in containers to complete their development. Greenhouse-grown trees are grown in containers in the greenhouse and are propagated by tip grafting only. When both types of trees are sold to home growers at the retail nursery, field-grown trees are older (12–18 months old), larger, and have been hardened to outdoor conditions. Greenhouse-grown trees are sold at a younger age (8–12 months). They are

smaller, have a more delicate root system, and require more careful attention after planting, particularly during the first year. They are less expensive than field-grown trees. Usually, greenhouse-grown trees have a lighter-textured leaf and more tender growth overall, but it may not be obvious that a particular tree is greenhouse grown rather than field grown, so make your preference known to the nursery when you order your trees.

Two voluntary programs of the California Department of Food and Agriculture (CDFA) allow wholesale avocado nurseries to register and certify trees sold to avocado growers if they are produced under specific conditions that minimize root rot. These conditions include heat-treating the seed, fumigating the potting soil, fencing the nursery site, isolating the nursery from known root rot infection, and other phytosanitary precautions. Registered trees are grown on clonal rootstocks tolerant to root rot and are also propagated from trees free of sunblotch viroid. Registered avocado trees sold to growers actually have three registrations: the nurse seed that starts the process, the rootstock, and the scion cultivar.

Planting

Before planting an avocado tree, it is advisable to know the history of the soil at the site you have selected. If the soil has been infested with *Phytophthora cinnamomi*, the fungus-like organism that causes avocado root rot, you might consider a different location or a different tree crop. At the very least, you will be apprised of the obstacles to be overcome and will have a realistic understanding of the likelihood of success. The clonal rootstocks that UC has developed are somewhat tolerant of root rot, but they are not totally resistant. While their increased benefits are available to the commercial grower, the home gardener may not have access to them because retail nurseries typically do not sell these clonal rootstocks absent a special request. Thus, if you determine that the soil has been infested with *Phytophthora cinnamomi* and you do not have another site, you might consider hiring a registered, professional pest control operator to treat the soil before planting. Additionally, you should consider purchasing a more expensive clonal tree by special request, due to its known higher tolerance to root rot.

If you cannot plant your tree immediately after delivery, store field-grown trees in full sun. Store greenhouse-grown trees where they will get morning sun but will be shaded in the hotter part of the day. Keep the soil moist on stored trees until you can plant them.

The optimal time to plant avocado trees is March, but April, May, or June may be suitable, especially near the coast. If your site is in a cold location, plant the tree(s) as soon as possible after the danger of frost has passed to take advantage of the longer growing season. The earlier the spring planting date, the greater the tree growth the first year. Trees planted after June are smaller and less tolerant of adverse weather during the first winter than trees planted earlier in the year. Where summers are hot, trees planted earlier are less likely to be heat injured.

How to Plant an Avocado Tree

A fully-leaved subtropical evergreen tree, such as an avocado, must be treated differently from a typical bare-root, deciduous temperate fruit tree. The following discussion of planting an avocado tree is summarized from *Planting and Management of Citrus and Avocado Trees* (Brokaw Nursery n.d.).

In most locations, avocado trees are often planted later in the spring than temperate fruit trees to take advantage of warmer soil. Special allowance must be made for an avocado's high transpiration rate. Avocado trees have tender, succulent roots, so their earthen balls may not be as physically stable as those of other plants. Therefore, do not lift or carry avocado trees by grasping the trunk because doing

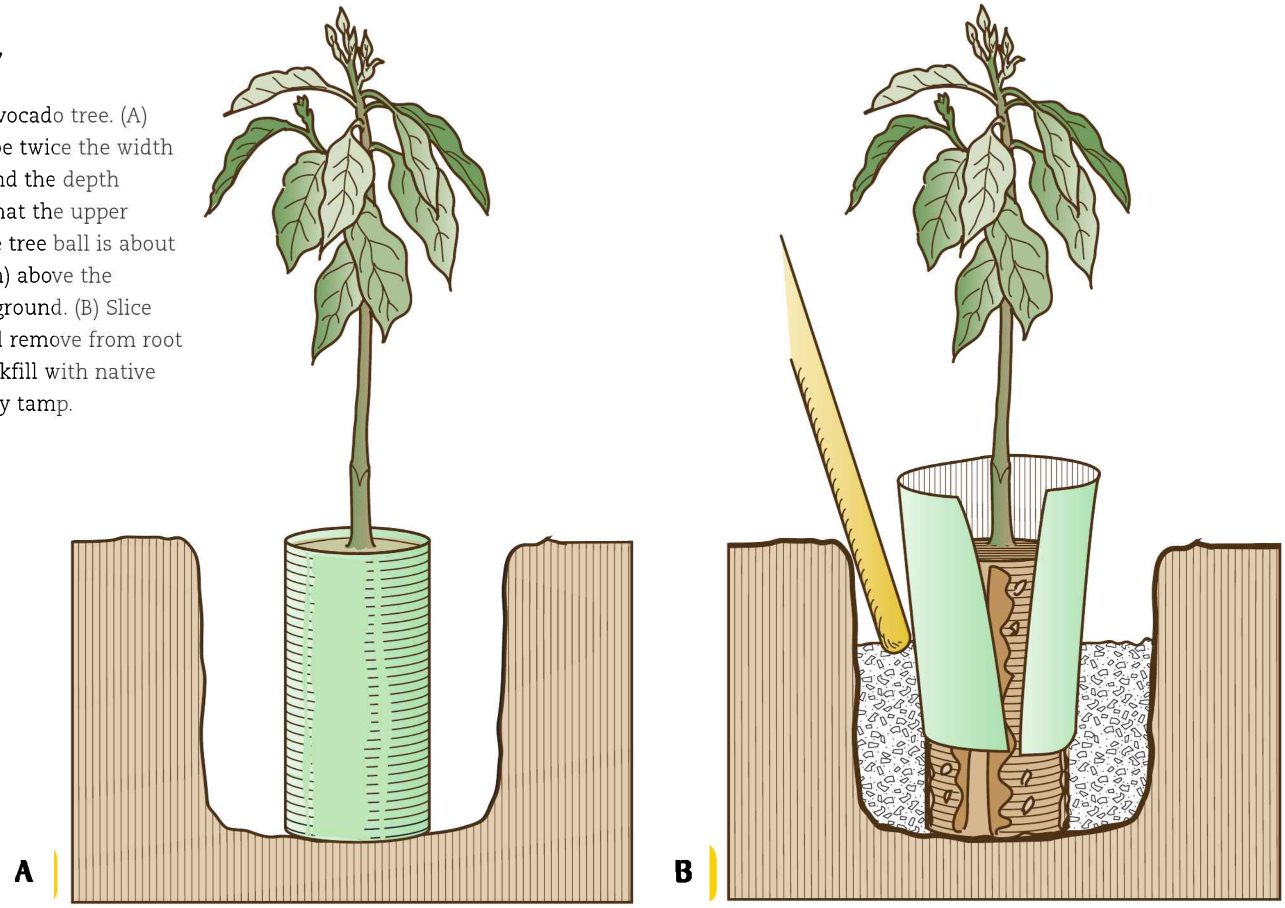


Figure 18.7

Planting an avocado tree. (A) Hole should be twice the width of root ball and the depth adjusted so that the upper surface of the tree ball is about 1 inch (2.5 cm) above the surrounding ground. (B) Slice container and remove from root ball, then backfill with native soil and gently tamp.

so often results in part of the root ball and soil breaking off. Be sure the tree is lowered into and correctly set in the planting hole before you slit the poly container.

Dig a hole much wider than the ball of your tree. In general, the hole should be about as deep as the root ball and about twice its diameter (fig. 18.7A). For a tree in a 3.5-gallon sleeve, an ideal hole is about 16 to 18 inches wide and about 20 inches deep. Save the soil for backfill. If your soil is not too light (sand) or heavy (clay), you do not need to add soil amendments to the hole. UC farm advisors recommend that you do not use soil amendments at planting time unless extreme conditions exist, such as adobe clay soil.

Adjust the depth of the hole so that the upper surface of the tree ball is about 1 inch above the surrounding ground when the tree is lowered into it. Moist soil against the trunk above the original soil line increases the risk of disease.

Lower the tree into the hole. Slice the container open vertically on one side. Backfill with 6 to 8 inches of loose soil (which should fill the hole about one-third full) to stabilize the tree before removing the slit container (fig. 18.7B). Do not move the root ball after the container is slit.

Take the plastic tube container out of the hole and place it away from the tree to be discarded. The poly container is recyclable but not degradable. This procedure will leave the roots exposed on the surface of the ball. Note that many of the roots are concentrated at the outside of the vertical surface.

Gently tamp the loose soil around the ball immediately. Promptly fill the rest of the hole with loose soil, gently tamping as you fill. Fill it to the top, but leave the upper surface of the original ball exposed.

The soil used to backfill the hole should be free of large clods because

they can cause large air spaces that prevent fine roots from contacting the soil and are detrimental to water movement through the backfill.

The upper surface of the ball is left exposed so that you may add water directly to the ball, even after the tree is planted. It is best to leave the upper surface exposed because the soil in the ball may have been specially formulated with nutrients and designed so the ball will readily absorb water applied to its upper surface. If you cover this surface with anything, do not use soil; use sand, loose sawdust, or coarse gravel, to allow water to pass through very rapidly.

At the time of field planting, protect any exposed parts of the stem from sunburn by painting them with a mixture of one-half water and one-half interior white latex paint; nonlatex paints damage tender plant tissue. Stake the tree for a year, longer in windy areas (see chapter 12, "Woody Landscape Plants," for tree staking technique).

Because avocado trees have shallow roots, the soil around them should not be disturbed by cultivation. Control weeds with frequent mowing, hand-weeding, or mulches. Mulches have several advantages, as noted later in this chapter. Herbicides should be used only as a last resort and must be applied carefully so as not to harm the tree. Use only herbicides labeled for use on avocados and follow label directions.

Water the tree immediately after planting and keep the root ball moist until roots grow out into the surrounding soil. The surface roots concentrated at the outside of the ball will die if they dry out.

Protecting Avocado Trees

Sunburn and Wind Protection

Both greenhouse-grown and field-grown avocado trees require protection from extremes in climate and from rodents. To protect greenhouse-grown trees, place cardboard cylinders 10 to 12 inches in diameter and 12 to 15 inches in height around the tree. Small trees may be completely enclosed by the cylinder. In time, the tree will grow out of the cylinder. On hot days, the air temperature inside the cylinder may become hot enough to damage tender stems and leaves. To provide air circulation, punch several holes in all sides of the cylinder or attach the cylinder to a stake and drive the stake into the soil beside the tree until the bottom of the cylinder is 3 inches from the soil level. This will allow air to flow freely through the cylinder (fig. 18.8).

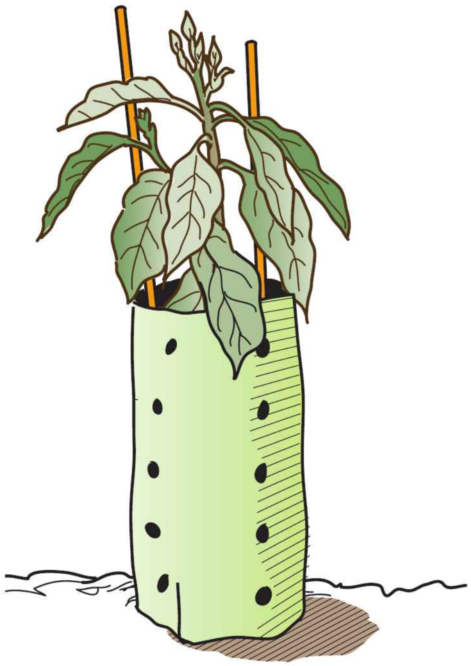
To protect field-grown trees, use a small, waxed, cardboard protector stapled or tied around the lower portion of the tree. If you use twine to hold the protector in place, be sure the twine is loose enough to allow the tree to grow without constriction. Later, when tree growth causes the tie to become tight, loosen or remove the twine. Do not use black building paper; it absorbs too much heat, which can be harmful to a tender trunk. Never use wire, paper-covered wire, or heavy plastic bands for ties; they can cause severe damage due to girdling if not loosened or removed as the tree grows. Place the protective cover so it reaches from near soil level to at least 6 or 8 inches above the bud union.

Tree protectors provide protection from sun, wind, and rodents; they do not protect trees from frost unless they are made of insulated materials and wrapped snugly around tree trunks. If it is likely that strong winds may damage trees, tie the trees to 2-by-2-inch stakes for protection. If you use plant stakes, you can attach the protective cylinders to them.

Frost Protection

If your only option is to plant avocado trees in a cold location, consider planting only cultivars known to be tolerant to frost (see table 18.1). Cold damage varies and depends on the duration of the cold,

Figure 18.8



Sunburn protection.

the season in which it occurs, the stage of tree growth, tree health, and similar factors. Fruit and stems may be damaged if temperatures remain below 28°F for any length of time. If your planting site is located where temperatures frequently fall below freezing, provide some form of frost protection. Tree wraps, if made of insulated material, provide some degree of stem protection. During the first winter, cornstalks or palm fronds placed firmly around the tree trunk and held securely in place can also be effective for protecting the stem and some of the foliage. For only one or a very few trees, it may be practical to erect a tent. Four posts with a plastic tarp (or other solid material) placed over them should be constructed so that nothing touches any part of the tree and so that heat is prevented from escaping. (For additional information on frost protection, see the related discussion in chapter 17, “Citrus.”)

When damaging freezes do occur, UC has developed techniques that maximize desirable growth responses. See the section “Treatment of Freeze-Damaged Avocado Trees,” later in this chapter.

Watering

Timely irrigation is essential for proper avocado tree growth, development, and fruiting. In the backyard, more trees become stunted and die due to drought stress than any other cause. Never allow the ball to dry out. Avocado trees are extremely sensitive to excess water, which can be caused by overirrigation or poor soil drainage. The root fungus *Phytophthora cinnamomi* thrives in saturated soil. Since avocado trees are evergreen, they need water year-round. Demand for water is high when trees are growing actively, which usually occurs from late winter or early spring through the summer. Demand is highest when evapotranspiration (ET) is highest, usually in the summer months. The most critical period for irrigation is from the year’s initial growth flush until the young fruit are at least 1 inch in diameter.

Trees cannot perform well if denied a quality water supply. Irrigation water should be relatively free of salt and toxic ions such as sodium and chloride. Irrigation water should not come into contact with the base of the tree trunk because such water may encourage fungal diseases such as Phytophthora root rot and Phytophthora trunk canker, which can kill the tree. The trunk and the bud union should stay dry.

Water the tree immediately after planting, because the surface roots concentrated at the outside of the ball will not be able to function properly unless they are kept moist. The tree’s active, working leaves must be supplied with water at all times to ensure proper functioning. Irrigate young trees with about 8 to 10 gallons of water each week. Three excellent irrigation methods for avocado trees are basin flooding, sprinkler irrigation, and drip irrigation.

Basin-Flooding Young Trees

Build a basin with a 3-foot diameter around the tree (fig. 18.9). The basin should have a capacity of about 5 gallons.

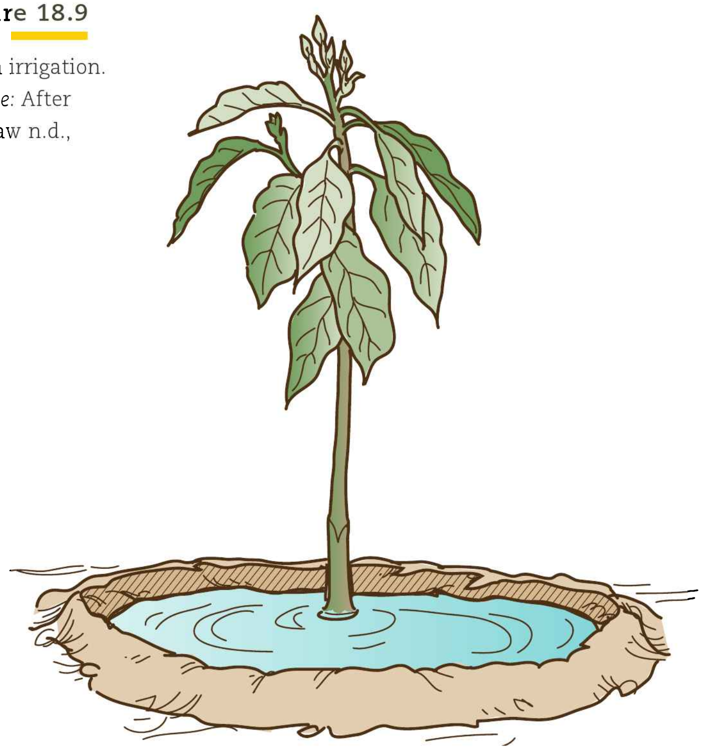


Figure 18.9

Basin irrigation. *Source:* After Brokaw n.d., p. 1.

Fill the basin with water once. If it drains rapidly, fill it again. If it requires 2 minutes or more to drain, do not refill. During the first year, fill the basin with water until the water penetrates just below the bottom of the original plant container. Eventually, the water will need to penetrate 2 to 3 feet. If the soil or root ball has settled, adjust the bottom of the basin, but be sure the top of the ball is still exposed. Once the basin has stabilized, the bottom of the basin can be covered with straw, sawdust, or some other mulching medium. Basin irrigation can be used for up to 2 years, but the basin should be broken down during the wet season if water has any tendency to stand in it.

Sprinkler Irrigation

If sprinkler irrigation is used for avocado trees, enough water must be applied during an irrigation to wet most of the root system. Supplemental irrigation using a hose may be needed to keep the root ball of newly planted trees thoroughly moist. Construction of a basin, as in flood irrigation, is useful with sprinkler irrigation during the first year after planting because it aids in holding irrigation water over the root ball and facilitates the hand-watering that may be needed. Be sure sprinklers give a good distribution pattern and discharge water at a rate the soil will absorb without runoff.

As with citrus, avocado trees commonly fail to thrive if planted in a lawn because tree roots need different irrigation from turf. A lawn often gets frequent watering that may soak down only about 6 inches (the depth of many turf roots); deeper avocado roots will be too dry, while the upper avocado roots will be kept too wet and will suffer from insufficient oxygen. Avocado trees can coexist with deeper-rooted, drought-tolerant grass such as hybrid bermuda, so irrigation can occur much longer and less frequently, depending on the soil and weather. The tree may need some extra irrigations from a hose in the summer to aid in water supply and to leach out salts.

Drip Irrigation

Drip irrigation systems dispense water slowly, in gallons per hour rather than in the gallons per minute typical of lawn sprinklers. If you use drip irrigation, be sure that the emitter is fastened to the exposed ball of a newly planted tree with a U-shaped piece of wire or hook to prevent the dripper from creeping away from the root ball as the hose expands and contracts. Check emitters frequently to be sure that each tree is getting watered. Clogged emitters are a common problem.

Initially, place the emitter over the root ball. Once the tree is established and the roots start reaching out into the surrounding soil (usually about 1–2 months after planting), move the emitter away from the top of the root ball to a distance of about 6 to 8 inches. In the second year, it is best to use two emitters, one on each side of the trunk about 8 inches away from it. As the tree grows, more emitters can be added. A mature avocado tree (about 6 years old) may have 4 or 5 or more emitters (depend-

ing on the emitter discharge rate) spaced in a ring around the tree near the drip line (the imaginary line below the canopy edge).

Drip irrigation systems are quite flexible. You can adjust the amount of water applied, not only by changing the interval between irrigations or the length of each irrigation, as with other methods, but also by selecting emitter number and emitter discharge rate. You can also place the emitter(s) precisely where wanted.

Irrigation Frequency

Irrigation frequency is influenced by climate; thus, a set schedule will not work under all conditions year-round. Evapotranspiration losses increase during hot, dry, windy conditions and with longer days, and consequently the demand for water increases. The more leaves on a tree, the larger the total leaf surface area and the greater the transpiration water use. A densely foliated tree will use more water than a sparsely foliated one, and larger trees use more water than smaller ones. Soil type also influences irrigation frequency because of its effects on water-holding capacity. Disregard the dryness of the top inch of soil, which dries out rather quickly even though the underlying soil may still be moist. Since 80% of the feeder roots of mature avocado trees are in the top 6 inches of the soil, it is imperative not to let this soil dry out before irrigating. However, do not irrigate wet soil, because this can damage the tree's roots.

Because of variable weather factors (relative humidity, day length, temperature, wind speed, etc.) and variable soil factors, it is impossible to give specific instructions for timing irrigations. In general, the older and larger the tree, the more total water it needs, but it needs watering less frequently. A mature avocado tree with an extensive root system requires more water to wet the root zone than a young tree with a smaller root mass, but the young tree's roots dry out faster. A newly planted tree still has its roots in the restricted container ball, which is not large enough to hold much water, even for the little tree above it. If the weather turns hot, dry, and windy soon after planting, such a tree might need daily watering. Even after the young tree has sent roots into the surrounding soil, it still has a small root-water supply and is also susceptible to foliar and stem injury from drying. Young trees may need to be watered two or three times weekly in hot weather. Gradually, the amount of irrigation water is increased and the frequency is decreased as the tree matures and the root system grows more extensive. The sooner that the ground surface can be allowed to dry out between irrigations, the better. Keeping avocado soil soggy is a recipe for disaster. Saturated soil lacks air in its pore spaces and favors root rot disease.

Irrigation Amount

For information on average daily evapotranspiration (ET), see table 4.1 in chapter 4, "Water Management." The reference plant material that scientists refer to in comparing water use among plant species is a 4- to 6-inch-high stand of cool-season turfgrass when unlimited water is available. A mature avocado tree uses about 70% of the water listed in tables 4.1 and 4.2 in chapter 4, which can exceed 50 gallons per day in hot, dry weather (table 18.2).

In general, for a newly planted tree, 2 to 4 gallons of water per irrigation should suffice if the water is directed into the ball. Basin-irrigate as described above and do not let the root ball dry out. Water enough to encourage deep and extensive rooting. A soil core probe slanted in to reach the ball at 12 to 14 inches below the soil surface can provide information about soil water content in the middle of the root ball (fig. 18.10). For a mature tree, water should be applied at each irrigation to a depth of about 2 feet. During the summer, if leaf tip burn indicates salt accumulation in the soil, a heavier irrigation is needed to leach the salts below the root zone.

Maintaining leaf litter or an organic mulch on the soil surface reduces ET, helps maintain adequate soil moisture where needed, and reduces soil temperature. Therefore, do not remove the natural leaf litter (mulch) from your avocado tree. Take advantage of it.

Drought can cause serious fruit drop, especially of small fruit. Older fruit may still hang on the tree but will shrivel. When an avocado tree is water stressed, it will extract water from mature fruit, causing them to dry out and shrivel. Fruit serve as a water source for the tree when the tree is experiencing drought. Overwatering also causes problems for avocado trees due to increased disease, particularly from Phytophthora root rot, which flourishes in waterlogged soil.

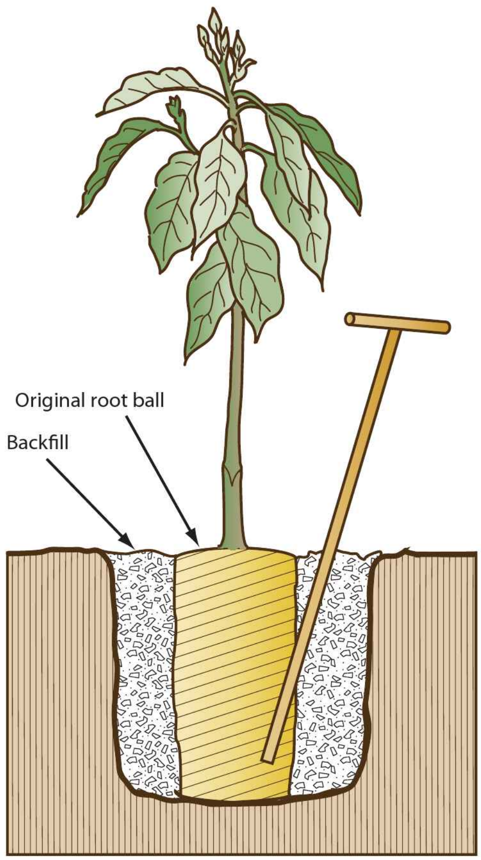


Figure 18.10

Using a soil probe to check soil moisture content near a newly planted tree.

Fertilizing

Avocado trees have comparatively few mineral deficiencies in California. Only nitrogen and zinc need to be applied extensively; iron chlorosis occurs occasionally. Fertilizer applications of these three nutrients are discussed below. Other nutrient deficiencies are rare in California avocados, even in areas where phosphorus, manganese, and magnesium deficiencies have been found on other subtropical fruit crops. Thus, additions of these nutrients are not recommended. Needless phosphorus applications may induce or aggravate a zinc deficiency.

Nitrogen

Nitrogen (N) is the most widely used fertilizer in California avocado production. For optimal yields, avocado trees need annual nitrogen fertilization. Young trees need only a few ounces of nitrogen per tree annually. Recently planted trees should be fertilized

Table 18.2.

AVOCADO IRRIGATION GUIDE

Canopy diameter (ft)	Mature avocado tree irrigation water requirements (gal/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20	7	13	20	29	40	47	53	47	36	20	9	7
18	7	12	19	28	37	44	51	44	35	19	9	7
16	5	11	17	25	33	39	45	39	31	17	8	5
14	5	9	15	23	29	35	40	35	28	15	8	5
12	4	9	13	20	27	31	35	31	24	13	7	4
10	4	7	11	14	21	25	29	25	20	11	5	4
8	3	5	8	13	17	20	23	20	16	8	4	3

Source: Adapted from Bender 1999.

Note: Spacing for trees is 20 ft by 20 ft. The water requirements of an avocado tree with this spacing approximate the water needs of a single, free-standing mature tree in the home garden.

Figure 18.11

Avocado leaves with adequate (upper) and deficient (lower) nitrogen concentrations. *Photo:* T. W. Embleton.

very cautiously until roots are well established. After roots are established, apply small amounts of nitrogen several months apart and eventually, as the tree grows larger, apply a larger nitrogen concentration in the spring through summer. Symptoms of nitrogen starvation include lack of vegetative growth; small, pale green leaves with yellow veins; lower yields; and premature defoliation (fig. 18.11). Nitrogen needs vary with the avocado cultivar. Commercial avocado growers use laboratory analysis of spring flush leaves from nonfruiting shoots collected in August through October to determine nitrogen nutrition in their trees and to guide fertilization practices. Where leaf analysis is not used, annual applications of 1/2 to 1 pound of actual (elemental) nitrogen per tree is suggested for mature trees. Excessive amounts on a tree of any size applied at any one time can cause root damage, leaf burn, and defoliation. In severe cases, trees may be killed.

Young trees

Fertilize with nitrogen sparingly to prevent harm, yet sufficiently to ensure maximum growth. The following program of soil-applied nitrogen fertilizer is suggested per tree for average conditions. If nitrogen is applied in a drip irrigation system, suggested amounts are given in table 18.3. In all cases below, the fertilizer should be broadcast evenly above the root system just before a rain is expected or irrigation is applied.

- First year: Apply 1/10 pound actual nitrogen annually, divided into equal monthly portions during the irrigation season (normally 8 months).
- Second year: Apply 1/5 pound actual nitrogen annually, divided into four equal portions during the irrigation season.
- Third year: Broadcast a total of 1/3 pound of actual nitrogen during March through October.
- Fourth year: Broadcast a total of 1/2 pound of actual nitrogen during March through October.

Nitrogen sources

Continuous use of ammonium sulfate for many years may make the soil too acidic, depending on the original pH of the soil. Continuous use of ammonium nitrate, anhydrous ammonia, or urea also acidifies the soil, but less rapidly than ammonium sulfate. Alkaline irrigation water tends to offset this effect. You may consider supplying part of the nitrogen in fall in the form of bulky organic matter, such as a

Table 18.3.

NITROGEN APPLICATIONS VIA DRIP IRRIGATION

Tree age	Amount per tree per month (lb)		
	Urea (46% N)	Ammonium nitrate (33% N)	Calcium nitrate (15.5% N)
first year	0.03	0.04	0.08
second year	0.05	0.08	0.16
third year	0.09	0.13	0.27
fourth year	0.14	0.19	0.40
fifth year and older	0.14–0.27	0.19–0.38	0.40–0.81

Note: Pounds of fertilizer material per tree per month during a typical 8-month irrigation season (Mar–Oct), which equates to rates of actual nitrogen (1/10 lb, year 1; 1/5 lb, year 2; 1/3 lb, year 3; 1/2 lb, year 4; 1 lb, year 5) given in the text.

manure that is cultivated into the soil. (Methods for calculating the nitrogen available in manures are provided in chapter 3, "Soil and Fertilizer Management.") If soil is or becomes too acidic (pH below 5.5), calcium nitrate should be used as a nitrogen source.

Timing of application for mature trees

The nitrogen requirement is greatest during the period of flowering, fruit set, and fruit maturation, approximately April through mid-August (Lovatt 2001). If adequate nitrogen is supplied for this period, there will usually be enough left in the soil to take care of the tree until the following spring. Chemical forms of nitrogen applied over the area occupied by the roots will be moved into the root zone by rain or irrigation water.

Zinc

Zinc (Zn) deficiency, commonly called mottleleaf, occurs in many avocado-growing areas in southern California. The avocado tree may decline and even die without a small, but essential, amount of zinc. The earliest symptoms of zinc deficiency are mottled leaves developing on a few of the terminals. The areas between the veins are light green to pale yellow (fig. 18.12). As the deficiency progresses, the yellow areas get larger, and the new leaves produced are smaller. In advanced stages, a marginal burn develops on these stunted leaves; twig dieback occurs; and the distance between the leaves on the stem is shortened, giving a crowded "feather duster" appearance. Yield is reduced, and some of the fruit may be more round than is normal for the cultivar.

Figure 18.12

Avocado leaves with deficient (left) and adequate (right) levels of zinc. *Photo:* T. W. Embleton.

Zinc deficiency can be controlled by applying zinc as a spray to the foliage or by applying it to the soil in some situations. Foliar applications require wetting the foliage with conventional pest control equipment. UC Cooperative Extension farm advisors recommend 1 pound of zinc sulfate in 100 gallons of water for commercial orchards, which can be reduced for the home orchard to 1 ounce per 6 gallons of water. Timing is normally not critical, but applications are most effective in June and July when spring-cycle leaves are two-thirds fully expanded but not hardened. Because zinc does not translocate readily from sprayed leaves to young growth after spraying, severely affected trees may require respraying several months later. However, there is evidence that zinc may not be as well absorbed by avocado leaves as once thought, making soil applications more attractive.

Soil applications of zinc have been successful on acid soil in San Diego and Santa Barbara Counties. Responses to soil applications have lasted up to 5 years, whereas foliar sprays must be repeated annually. The effectiveness of zinc applications depends on the soil type, the amount used, and the method of application. In commercial settings, the dosage per tree must be determined for each orchard. For home growers, no absolutely precise recommendation can be given. Suggested amounts of zinc sulfate (36% metallic zinc) are given in table 18.4. Material may be applied as a surface band or in holes augered into the soil about 6 inches deep around the drip line of the tree. Applications should be repeated every 3 to 5 years if trees continue to show deficiency symptoms.

Chelated forms of zinc may also be used, but they do not appear to have any

Table 18.4.

SUGGESTED AMOUNTS OF ZINC SULFATE FOR SOIL APPLICATIONS

	Dosage per tree (lb)	
Tree age (yr)	Surface band	Inserted in holes
2	0.7	—
5	2.0	0.7
7	2.6	1.3
10	3.3	2.0
15	5.2	2.6
20	6.5	3.3

advantages over zinc sulfate, and they are more expensive. On trees older than 10 years, the total zinc sulfate recommended should be divided into two or three applications about 1 month apart. Foliar applications provide zinc to deficient trees immediately. Soil applications provide zinc slowly and continuously to the tree over the months and years ahead.

Iron

Iron (Fe) deficiency is difficult to correct. The best thing to do is to test the soil pH before planting. If it is in excess of 7, the planting area should be treated with a mild acid like vinegar or elemental sulfur to lower the pH. The soil should be retested after treatment to make sure that the pH has been lowered. Lowering the pH reduces the need to treat for iron deficiency. In mild forms of iron deficiency, leaves show a network of green veins and veinlets against a lighter green background (fig.18.13). As the deficiency increases, the interveinal area becomes yellowish white, and the veins lose their green color. In severe cases, leaves are smaller, completely chlorotic (yellow), and show tip and marginal burn accompanied by defoliation and twig dieback. Iron chlorosis may occur on individual limbs or affect the entire tree, and yield may be reduced.

Iron deficiency usually occurs in high-pH soil containing lime (calcium carbonate), which limits the use of iron by the tree. The deficiency is accentuated by excess soil moisture and low oxygen content in the soil. The use of Mexican-race rootstocks, rather than Guatemalan, has minimized iron chlorosis. The most effective application methods are to inject iron chelates in solution into the root zone or to rake back the leaves, broadcast the material, and work it into the surface soil, pushing the leaves back and irrigating immediately. Often, just reducing irrigation frequency or amount will rectify the problem and save water as well.

Figure 18.13

Iron-deficient avocado leaves. *Photo:* T. W. Embleton.

Potassium

Potassium (K) deficiency can cause leaf edge necrosis, resembling tip burn, and brown spots between leaf veins (fig. 18.14). Avocado trees have more than 60 enzymes that need potassium to operate properly in photosynthesis and other metabolic functions. Recent research in California demonstrated that most of the potassium taken up by an avocado tree is found in the fruit. Potassium should be applied at approximately the same time as nitrogen (April–August), when uptake by the fruit is greatest. In most avocado-producing countries, potassium is applied in amounts equal to or slightly greater than nitrogen. Potassium nitrate is a good choice for providing both nutrients. Potassium sulfate is another source of potassium that also supplies sulfur, an

Figure 18.14

Potassium-deficient avocado leaves and young fruit. *Photo:* T. W. Embleton.

essential nutrient required only in small amounts by avocado trees. Potassium chloride is the most common form but will add too much chloride to the soil (fig. 18.15).

Pruning

Most avocado trees require little or no pruning by home gardeners. Whenever possible, allow trees to develop naturally, and you will avoid disturbing the balance between foliage and fruiting wood, which is essential for high yields. Prune avocado trees cautiously. An abundance of foliage, which manufactures food for the tree, keeps fruiting vigorous. If this food supply is reduced by severe pruning, fruit yield will suffer.

Figure 18.15

Healthy avocado leaf (left) and leaves showing the effect of chloride accumulation over time. *Photo:* T. W. Embleton.

Pruning avocado trees may

- control the height of tall cultivars
- correct poor growth habits
- prevent wind damage
- regulate severe alternate bearing

But it may also

- stunt full tree growth
- reduce yield
- stimulate foliage growth at expense of fruiting
- make trees susceptible to frost injury and to fungal pathogens that enter through pruning wounds on the bark surface
- if too drastic, may remove fruiting wood

Avocado trees grow irregularly, and most develop a better structure if they are not pruned at all. Nevertheless, the height of some cultivars can make harvesting difficult. An avocado tree may grow too tall for a backyard, with most of the fruiting in the top of the tree. If you determine that pruning is necessary, follow these four simple rules:

1. Prune sparingly. Remove as little green wood and as few green leaves as possible. Prune only after the tree has developed sufficient upper foliage to prevent sunburn.
2. Avoid pruning in fall. Pruning at this time stimulates vegetative growth and may make trees susceptible to frost injury. Avoid pruning soon after rainfall to reduce the spread of fungal pathogens. Prune only when it is dry.
3. Make pruning cuts as close to a lateral branch as possible. The greatest growth stimulation is nearest the cut. Removing large branches stimulates vegetative growth over the entire tree. Please refer to chapters 12, "Woody Landscape Plants," and 5, "Plant Propagation," for general information about pruning cuts.
4. Let pruning wounds dry out naturally. Research has shown that healing of pruning wounds is not hastened by covering with tree sealants or wound

dressings. Dry pruning wounds close naturally and are less susceptible to wood rot.

More-erect trees may be tipped repeatedly (pinch back the terminal bud and repeat after each growth flush) to develop a bushier, more compact shape. Pruning low-hanging branches may keep fruit off the ground or make irrigation management easier, but keep pruning to a minimum. Heavy cuts on low branches force growth upward. Removing deadwood makes picking easier and controls pests by disposing of inoculum sources. In coastal regions, removing deadwood may help prevent Dothiorella rot, which causes avocado fruit to decay when softening.

Since avocado trees grow irregularly and different cultivars have individual growing habits, it is difficult to give general pruning directions that apply to all trees. You may have to experiment to develop the pruning methods best suited to your trees. The tree's scion cultivar and vigor, along with soil and climate conditions, should influence your pruning practices. In some instances, no pruning will be needed at all. Fruit thinning is typically not needed on avocado trees unless too much fruit is set and could break branches. Even then, bracing the branch is usually a better solution. On young trees, thinning is sometimes practical because very heavy crops can reduce the vitality of the tree. However, leaving fruit on the tree slows the growth of trees and keeps them from becoming too large too quickly.

Mulching

Mulches have numerous benefits in the cultivation of avocado trees, including suppression of *Phytophthora cinnamomi*, the cause of avocado root rot, the most serious avocado disease worldwide. Yard waste (wood chips, grass clippings, and leaves), straw (grain or bean), wood shavings, alfalfa meal, or any inexpensive organic material can be used for mulching. If straw is used, beware of potential damage from field mice and rats since they often make nests in straw. Do not use mushroom compost or animal manure until trees are at least 3 years old because these materials may contain excess nitrogen (ammonia) or soluble salts that can be leached into the root zone and injure roots or cause tip burn of the leaves. (Methods for calculating the nitrogen available in manures are provided in chapter 3, "Soil and Fertilizer Management.") Several benefits of mulching avocado trees are discussed briefly below. This discussion of mulching is adapted from Turney and Menge 1994.

Control of Avocado Root Rot Disease

Thick mulches applied to the soil surface can create conditions harmful to pathogenic soil organisms, such as nematodes and the oomycete *Phytophthora cinnamomi*. Alfalfa meal mixed with soil at rates of 1 to 5% and alfalfa straw have often provided good control of Phytophthora root rot in avocado. In California, intensive mulching combined with applications of gypsum ($CaSO_4$) has controlled Phytophthora root rot in avocado. Research has indicated that when the soil's organic matter content is kept in the range of 7% with the use of organic mulches, the soil becomes suppressive to *P. cinnamomi*. Several mechanisms have been proposed to explain why mulches can reduce Phytophthora root rot in avocado:

- Mulching increases the population of soil microbes that can compete with or inhibit pathogens.
- Soil amended with alfalfa meal or other decaying organic matter is known to have higher concentrations of gases, such as ammonia, that can inhibit Phytophthora.
- Mulches create a natural litter layer favoring the proliferation of tree roots and disfavoring Phytophthora infection. The interface of soil surface and mulch is a natural microenvironment where roots grow well but where *Phytophthora* cannot survive. *Phytophthora* needs saturated soil conditions to release its spores, which must then swim to tree

roots to cause new infections. But water drains so quickly from the mulch layer that saturated conditions may not last long enough for spores to be released and come into contact with tree roots.

Chemicals produced during the decomposition of organic matter in mulched soil, such as ammonium (NH_4^+), saponins, phenolics, and nitrite, are toxic at low concentrations and prevent propagule germination in *P. cinnamomi*, thus retarding disease development.

Organic matter can entrap spores, preventing them from coming into contact with plant roots.

Soil gases and compounds released during organic matter decomposition in the mulch can increase the level of host (avocado) resistance in the roots to *Phytophthora*.

The incorporation of calcium into mulch in the form of gypsum appears to have a critical role in reducing avocado root rot. Scientists have shown that entrapment of spores and host resistance are enhanced with additions of calcium in mulch. Soil with poor infiltration and high expendable sodium has the highest incidence of avocado root rot. Organic mulches combined with applications of gypsum increase soil drainage and displace excess sodium from the upper soil profile, which renders the soil less conducive to root rot caused by *Phytophthora*.

Reduction of Weed Problems

If mulches are at least 2 inches thick, they can reduce weed problems by preventing germination of most weed seeds. Avocado trees are more productive if they do not have to compete with weeds for water and essential nutrients. When weeds do grow, it is best to hand-pull them because cultivation equipment can damage the tree's surface roots. However, if you use a weed whacker around the tree, be careful not to cut the bark of the tree.

Conservation of Water

Mulches can conserve water by reducing evaporation from the soil, reducing runoff and erosion, increasing the permeability of the soil surface, and increasing the water-holding capacity of the soil. At field capacity, mulched soil with high organic matter content has more water available to trees.

Improvement in Soil Physical Properties

Organic mulches can improve soil physical properties by increasing the soil's organic matter content, which results in aggregation of soil particles and increased pore size distribution, improved water infiltration, and better gas exchange (carbon dioxide and oxygen). This facilitates the use of the top 12 inches of soil, where avocado roots are most active.

Improvement in Nitrogen Fertility

Mulches can eliminate or reduce nitrate contamination of groundwater by providing a continuous, slow release of nitrogen, reducing the need for nitrogen applied as chemical fertilizer. Mulches with a high carbon-to-nitrogen ratio may cause a short-term initial nitrogen depletion due to the increased populations of microorganisms produced during the early decomposition process, which requires continued nitrogen fertilization for a short period of time until the mulch is decomposed further. However, the long-term benefit of decomposed mulch is the slow and increased release of nitrogen to the soil. Organic mulches also supply several other essential plant nutrient elements, in part because they increase the soil's cation exchange capacity, which increases the availability of many nutrient elements to plant roots.

Improvement in Soil Temperature

Mulches can reduce wide fluctuations in soil temperature by reducing the soil's absorption of heat. This is beneficial to root growth, especially in young trees and in areas where summer temperatures are very high. Lower soil temperatures are also less favorable to *Phytophthora*. However, when frosts are predicted, remove mulch, if possible, because bare soil can absorb more radiant energy than most mulches.

Harvesting and Storage

Unlike citrus, avocados do not become edible on the tree. They mature on the tree but must be severed from their stems and held for several days to ripen, that is, to soften for edibility. Harvest by cutting the stem with hand clippers as close to the fruit as possible without injury. Protruding stems may injure other maturing fruit, and pulling fruit from the stems can leave wounds that invite rot. Do not harvest when it is raining because stem-end rot pathogens can be spread by rain splash to harvested fruit, leading to their discoloration and decay. Even though fruit can be exposed to stem-end rot pathogens (fungi) before harvest, most symptoms and infections do not occur until after harvest when fruit have a reduced concentration of fungal inhibitors.

Table 18.1 gives a basic guide to the maturity seasons of the different scion cultivars, but the precise maturity season can vary, depending on the climate zone, the weather in a particular growing season, and other factors. As expected maturity approaches, pick a couple of the more mature-looking fruit and allow them to ripen to test palatability. Fruit size is not a good maturity indicator. Purple or black cultivars are usually mature when the fruit begins to turn from green to dark. Cultivars whose skin stays green at maturity and during ripening change from a bright green to a duller, yellower, or grayer green, often with small corky areas (rusty brown specks) on the skin. The number of days from harvest to ripeness varies with the cultivar and decreases with a higher level of maturity and temperature; room temperature is about optimal. Mature fruit ripen in a reasonable time to good consistency without appreciable shriveling or creasing, which means that the flesh is soft without staying rubbery or having hard areas and without a bitter or "green-bark" immature flavor.

To determine when an avocado is soft enough to eat (ripe), hold the fruit in your palm and gently squeeze with your whole hand; a uniform, slight softness without a rubbery feel indicates ripeness. The thumb is usually the most sensitive tester, but be careful not to press so hard as to leave a discoloring bruise in the ripe or near-ripe fruit. These ripeness-testing techniques soon become second nature. Feel, not color, is the final authority on ripeness. Color indicates maturity rather than ripeness; however, some fruit of a black cultivar will turn from green to black only as they ripen.

Once you have determined that your avocado fruit are palatably mature, you can pick them as needed, harvesting the number of fruit wanted with a lead time in days corresponding to the estimated ripening time. In practice, this usually means having one or more mature avocados in the process of ripening and one or two ripe avocados stored in the refrigerator. For successful postharvest storage of ripe avocado fruit, UC researchers recommend temperatures of 41° to 46°F (refrigeration) for no longer than 1 to 2 weeks. Fresh-picked, mature fruit that are refrigerated before ripening may never soften properly. But fruit that are half-ripe can be stored in the refrigerator for up to 3 weeks or so and should ripen just fine. Avocados ripen in 2 to 5 days when placed in a paper bag with a banana or an apple. This sort of flexibility, combined with long on-tree storage of mature fruit in the better avocado cultivars, means that backyard growers can eat avocados off their trees daily for 6 months or more. In addition to certain availability, backyard growers can be even more certain of high fruit quality.

Avocado Diseases, Insect Pests, and Environmental Stresses

Compared with other deciduous fruit tree crops grown in the home garden, such as apples and peaches, avocados have relatively few pest and disease problems if they

receive good care. Healthy trees that are irrigated and fertilized properly should have little pest damage. Many avocado trees in California produce for decades or a lifetime without any disease treatment whatsoever. This is especially true for the home gardener for whom maximum fruit production and absence of commercial culls are not important issues.

California is under constant threat from new avocado pests that are native to Mexico and Central and South America, the areas where avocado is native. Increasing imports of fresh fruit from these areas increases the likelihood of accidental introduction. It is critical that growers of avocado in the home garden be diligent in finding and identifying new pests. Unusual feeding damage should be investigated quickly; digital photos can help greatly with diagnoses. Below is a brief description of three dangerous avocado pests to be on the lookout for, each with a website to consult for photos and additional information.

Avocado seed moth *(Stenoma catenifer)* is one of the most destructive fruit-feeding insects known to attack avocados. Larvae bore into fruit, damaging the pulp to feed on the seed. Infested fruit are very easy to identify by the presence of holes on the sides and bottom of the fruit from which frass is being pushed out by the feeding larvae. White stains may also be present on the fruit skin below these holes (see the UC Riverside Applied Biological Control website, biocontrol.ucr.edu/stenoma/stenoma.html).

Avocado leaf galling psyllid (*Trioza* spp.) feeding nymphs cause leaf rolling or curling or striking cone-shaped projections that erupt from the surface of infested avocado leaves (see biocontrol.ucr.edu/hoddle/trioza/trioza.html).

Polyphagous shot hole borer and fusarium dieback is a new beetle-fungal complex that was detected on avocado and other host plants in Los Angeles, Orange, San Bernardino, Riverside, San Diego, and Santa Cruz Counties. The fungus *Fusarium euwallaceae* forms a symbiotic relationship with a recently discovered beetle that is commonly known as the polyphagous shot hole borer (PSHB, *Euwallacea* sp.). Together, they cause the disease Fusarium dieback (FD). When the beetle burrows into the tree, it inoculates the host plant with the fungus, which is carried in its mouthparts in a structure called mycangia. The fungus attacks the vascular tissue of the tree, blocking the transport of water and nutrients from the roots to the rest of the tree, and eventually causing branch dieback. The beetle larvae live in galleries within the tree and feed on the fungus. FD has been observed on more than 210 different species in California, including many species common in urban landscapes and on such agriculturally important species as avocado, olive, and persimmon (see the UC Riverside Eskalen Lab website, eskalenlab.ucr.edu/avocado.edu).

Avocado branch canker and stem-end rot. Species in the fungal family Botryosphaeriaceae are known to cause branch canker and stem-end rot on avocado. These diseases can be controlled using best management practices. During pruning, equipment should be disinfested and sanitized by dipping tools into a 5% bleach solution (1 part household bleach with 4 parts water) before you start pruning and between cuts to different branches. To counteract the corrosive action of the disinfectant, clean pruning tools after use in a mixture of 2 teaspoons of emulsifiable oil in ½ cup of vinegar diluted with water to a total volume of 2 cups. This mixture should be shaken vigorously just before use. In addition, store harvested fruit at optimal temperatures. Often, the first sign of stem-end rot is postharvest shriveling of fruit around the base of the stem after which the fruit has internal discoloration and decays.

Report suspected new pests to specialists at the University of California (see the UCR invasive species website, cisr.ucr.edu),

the local county agricultural commissioner, or the California Department of Food and Agriculture (see the CDFA invasive species website, cdfa.ca.gov/invasives/). Please include all relevant documentation when forwarding pest reports of concern (e.g., location, data, and photos used for diagnoses).

Table 18.5 lists the most common avocado diseases, insect and mite pests, and environmental stresses and also describes what the symptoms look like, indicates the probable causal agent and plant part(s) affected, and comments on control measures. Although table 18.5 is long, it should not be discouraging because proper irrigation, fertilization, and cultural practices can prevent the majority of the problems listed. The information in table 18.5 has three purposes. First, it stresses prevention; for the major avocado diseases, the best control measure is to avoid the problem in the first place. Second, it provides guidance when problems do appear, helping the backyard grower decide whether to seek advice from the local UC Cooperative Extension farm advisor, apply treatment, live with the problem, or, as a last resort, remove the tree. Finally, for the gardener who is seriously interested in avocados, table 18.5 provides a deeper understanding of the crop and its reactions to environmental influences. For additional information and color photographs of avocado pests and diseases, and the most recent UC recommendations for pest and disease control, consult the UC IPM Avocado Pest Management Guidelines, ipm.ucdavis.edu/PMG/selectnewpest.avocado.html.

An important point that cannot be overemphasized is that many of the problems noted in table 18.5 are more likely to occur in trees under stress. By providing good care, especially irrigation and fertilization as needed, the backyard grower can do much to minimize the chances of an occurrence of the problems. For example, a water deficit can injure the whole tree and make it more susceptible to several pests. Conversely, excess water (from overwatering or from failure to provide surface drainage for heavy winter rains) can open the door to Phytophthora root rot or asphyxiate roots, injuring the tree and making it more susceptible to pests and other disorders.

Control Measures

Mechanical control

Mechanical methods are nonpolluting, nonpersistent pest control techniques, such as removing diseased fruit and branches, cleaning up debris, dislodging pests such as whiteflies and mites with strong blasts of water from a garden hose, handpicking and disposal of snails and slugs, washing off dust to facilitate better biological control of avocado pests, and setting up mechanical ant barriers. Soaps and oil sprays are two types of mechanical control that are effective against a number of soft-bodied insects and mites.

Insecticidal soaps. Soaps are safe to use even on edible plant parts. They are effective against soft-bodied insects and mites on contact by penetrating their cell membranes and killing them without harming trees or fruit. You can purchase insecticidal soaps at most nurseries. Soaps are best applied in the early morning or late afternoon. Use soaps only when your trees have been well irrigated and when conditions are not windy and not too hot (< 90°F).

Summer oils. Special horticultural oils have long been used on dormant deciduous trees to smother and kill soft-bodied insects and mites. However, for evergreens like the avocado, more refined oils, labeled Supreme, Superior, or Narrow Range, should be applied to kill mites (and their eggs), whiteflies, scales, and mealybugs. Avoid spraying horticultural oils in foggy and humid weather because the oil will dissipate so slowly that leaf and stem injury can occur on the tree.

Biological control

Biological control is generally more effective on avocado in coastal regions than in

Table 18.5.

PROBLEM DIAGNOSIS FOR AVOCADO

What the problem looks like	Probable cause	Comments
MICROSCOPIC DISEASE-CAUSING ORGANISMS (PRIMARILY FUNGI OR FUNGI-LIKE)		
Small, pale green, wilted leaves. Sparse foliage. New growth absent or if it occurs, new leaves small with poor color. Small branches die back at top of tree, allowing other branches to become sunburned due to lack of foliage. Small, fibrous feeder roots absent or, if present, blackened, brittle, dead.	avocado root rot *(Phytophthora cinnamomi)*	A fungus-like organism (oomycete) with more than 1,000 hosts. Attacks small feeder roots. The most serious avocado disease in California. *Phytophthora* thrives in excess soil moisture (overirrigation and poor drainage). Attacks trees of any size or age. Absence of feeder roots prevents moisture uptake so the soil under diseased trees stays wet even though tree appears wilted. Roots of pencil size or larger seldom attacked. Diseased trees may set a heavy crop of small fruit but will decline and die, either rapidly or slowly. The disease can spread by contaminated nursery stock, water in contact with infested soil, shoes, and cultivation equipment. Control measures: Use an integrated approach of prevention, culture, treatment. Prevention: Plant on soil with good internal drainage; avoid overwatering; use clean nursery stock, preferably certified disease-free; use resistant rootstocks (resistant does not mean immune); prevent soil or water movement from infested areas. Disease treatment: Check UC IPM Avocado Pest Management Guidelines, www.ipm.ucdavis.edu, for any current control strategies and practices. Replant infested sites with immune plants. Even though *Phytophthora cinnamomi* has a wide host range, there are many garden plants that are not susceptible, including all cultivars of *Citrus*, cherimoya, all types of vegetables, most annual flower crops, and many deciduous fruit trees and berries.
Poor growth, loss of tree vigor. Small, yellowing leaves; premature leaf drop; wilting, collapse. In winter, clusters of mushrooms form at base of infected trees a few days after a rain. White, fan-shaped fungus mycelium grows under bark of diseased roots.	Armillaria root rot *(Armillaria mellea)*	Also known as oak root fungus. Attacks roots. Visible symptoms may not appear until fungus is well established in the roots. Can destroy entire root system and kill tree. Once symptoms appear, it is very difficult to save a tree, and disease may have spread to roots of adjacent trees. After aerial parts of infected trees are dead, the fungus remains alive in the roots to infect any replanted, susceptible trees, such as citrus, peach, or avocado. Let soil dry out between irrigations.
Poor growth, loss of tree vigor. Chlorotic (yellowing) foliage. Poor fruit production. Cankers on trunk and branches. Leaf blotching, wilting. Rapid death of some new growth. Often death of entire tree eventually.	avocado black streak (ABS)	Causal organism unknown. Attacks trunk and branches. Present in California for more than 60 years but observed only on Guatemalan cultivars, such as Hass and Reed, and only after prolonged stress. Since many symptoms are similar to those attributable to other causes, cankers on trunk and branches are diagnostic of ABS. Cankers vary in size and have a dry, powdery, water-soluble sugar that exudes through tiny cracks in the bark. Shallow, red-brown lesions under cankers are revealed when bark is removed. Management of ABS consists of maintaining tree health with good fertilizer and irrigation practices. Remove unhealthy trees.
Leaves suddenly wilt on one part of tree or on the entire tree and then turn brown and die but do not drop off for months. Brown to gray-brown streaks are visible in wood of branches or roots (plugged xylem tissues).	Verticillium wilt *(Verticillium albo-atrum)*	Attacks xylem tissue. Enters roots and moves upward. May kill all or part of tree, with the remainder having complete recovery. Mexican rootstocks are more resistant than Guatemalan. Do not plant on soil that has been used for other crops susceptible to Verticillium wilt, such as tomato, eggplant, pepper, many berries, apricot, potato, and several flower crops. Do not plant any of these near an avocado tree.
Bark cankers exude white powder. Outer bark cracks and sheds easily. Diseased trees die back and may look unthrifty but rarely die.	Dothiorella canker *(Dothiorella gregaria)*	Attacks trunk and branches. A minor fungal problem favored by moisture. Keep irrigation water off tree base. Guatemalan rootstocks or scion tops are much more susceptible than Mexican. Control not usually needed. Scraping off outer bark removes some infection and encourages regeneration of vigorous bark.

Table 18.5. cont.

PROBLEM DIAGNOSIS FOR AVOCADO

What the problem looks like	Probable cause	Comments
Trunk cankers at base of older trees, originating at or below ground level. Canker appears as a dark region with a red, resinous exudate that dries to a white, crystalline deposit. Underneath the superficial canker is an orange-tan to brown lesion instead of the normal white or cream-colored tissue. Lesion has a fruity odor when exposed. As with its related species, *P. cinnamomi*, there may be a gradual decline over years or sudden tree death.	Phytophthora canker (collar rot) *(Phytophthora citricola)*	Attacks phloem tissue, lower tree trunk. Collar rot is now widespread in California, second only to avocado root rot in severity. As with all *Phytophthora* species, disease is favored by excess soil moisture, such as from overirrigation or poor drainage. The disease can be spread by contaminated nursery stock, irrigation water, and cultivation equipment. Use sanitation measures noted for other *Phytophthora* species. Seedling rootstocks are generally more sensitive than clonal stocks, such as Duke 7 and Toro Canyon. Since *P. citricola* is found increasingly together with *P. cinnamomi*, an integrated approach to control both is important. Do not allow the lower trunks of trees to stay wet. Place drip emitters away from tree trunks. Aim minisprinklers to avoid wetting tree trunks. Avoid wounding trunks. If cankers are detected at an early stage, they can sometimes be controlled by cutting out the infected tissue. No chemicals are currently registered for use on this disease.
Fruit hanging near the ground has a distinct, rounded black area, usually at the end toward the soil. Rot soon extends internally, sometimes to the seed.	Phytophthora fruit rot *(Phytophthora citricola)*	Attacks fruit. Limited to prolonged wet weather in a dry climate like California. Probably caused by disease organisms splashing up from the soil, so a mulch or leaf layer should help. Removing fruit that touches the ground will remove a likely source of disease inoculation since this soil oomycete can sporulate easily.
Unlike Phytophthora fruit rot (above), symptoms develop after fruit is picked and starts to soften. Purple-brown spots appear on fruit surface. Spots can enlarge until they cover entire fruit. Fruit flesh becomes discolored and has an unpleasant odor.	Dothiorella fruit rot *(Dothiorella gregaria)*	Attacks fruit. Like Phytophthora fruit rot, this disease is rarely important in our dry climate. When it does develop, it is usually on dead branches, leaves, and leaf margins. If needed, remove dead material. Do not let dead debris accumulate. Minimize leaf tip burn; avoid saline conditions because the fungus can live on the dead portions of leaves. See excess salts for more information. After picking, move fruit to a minimum of 41°F as quickly as possible. Ripen under 60°F (cooler than room temperature) to minimize rot.
Brown, scattered, dead areas on leaves, that, if extensive, cause severe leaf drop. Infected fruit develops small, dark spots at lenticels. Like Dothiorella fruit rot, major fruit rotting develops only upon ripening, after harvest; unlike Dothiorella, the flesh rots are many and smaller.	anthracnose *(Colletotrichum gloeosporioides)*	Attacks leaves and fruit. Becomes serious in California only with wet, mild winters. As with Dothiorella fruit rot, important to cool fruit quickly after picking and to ripen them at below room temperature, if possible. Removing dead material and pruning to open the tree canopy for better aeration are helpful, if needed. Spores germinate and penetrate the fruit before harvest, causing brown to black spots, but the disease does not develop further until after harvest. Resumes growth during ripening.
Active lesions on bark are dark, slightly sunken areas with watery, necrotic pockets under the surface. Bark splits on one side of canker and watery fluid oozes out and dries, leaving a white, powdery residue at the lesion. Cankers range in diameter from 1–4 in. Usually appear first at the base of the tree and often spread upward on one side of the trunk or branch.	bacterial canker *(Xanthomonas campestris)*	Attacks trunk and branches. Widespread disease but relatively unimportant in California. Most groves have a few infected trees without noticeable harm. Affected trees often have leaf symptoms of boron deficiency. If the disease is severe, affecting yield, the tree should be removed. Mild infections seem to have little effect and are too common and spread too little to justify tree removal.
Twigs have narrow, yellow, red, or necrotic shallow indentations that occur lengthwise. Fruit with white, yellow, or reddish blotches or streaks that may be depressed. Rectangular cracking of bark on trunk and larger branches, known as alligator bark. Tree in general is stunted, with sprawling growth.	sunblotch (avocado sunblotch viroid, ASBVD)	Small, single-stranded, circular RNA molecule. Attacks all parts of tree. Formerly caused devastation in California. Discovery in the 1970s that it is the result of a viroid (a smaller, "naked" virus) led to effective control. Purchase registered trees for which scion top and rootstock are indexed as viroid-free. Established infected tree can contaminate nearby healthy avocados by unseen root-to-root grafting and by human-mediated wound-to-wound cutting tools. Removal is recommended in such cases. Occasional symptomless trees can cause infection directly or through symptomless seedlings used in rootstocks. Sterilize pruning tools and harvesting clippers between trees.

Table 18.5. cont.

PROBLEM DIAGNOSIS FOR AVOCADO

What the problem looks like	Probable cause	Comments
MITES, INSECTS, AND GARDEN SNAILS AND SLUGS		
Light green or yellow areas on upper leaf surfaces along the midrib, later extending to the smaller veins and entire leaf. Areas of severe feeding later turn brown (bronzing of leaves) and leaves may drop.	avocado brown mite *(Oligonychus punicae)*	Tiny, brown-colored mite about the size of a period, the same size as the persea mite and the avocado mite. Attacks upper leaf surface. Trees injured in proportion to the amount of green leaf area lost. See persea mite for further details.
Light green or yellow areas on underside of leaves along the midrib and larger veins. Heavy infestations can cause leaf drop.	avocado mite	Tiny, yellow to pale green mite about size of a period; a pest of avocados primarily in coastal areas. Attacks underside of leaves. Formerly known as six-spotted mite. See persea mite for more details.
Small necrotic spots on the underside of leaves along the midrib and main veins. As population increases, new necrotic spots appear between the veins. Each spot is covered with fine webbing that shines silvery in sunlight. Necrotic spots can coalesce and block transport of carbohydrates from leaf cells to veins. At this point leaves drop, and if extensive, fruit drop follows.	persea mite *(Oligonychus perseae)*	Attacks underside of leaves. A yellowish mite about the size of a period. This mite pest, a native to Mexico, was first detected in California in 1990. It spreads rapidly since its webbing protects it and its eggs from the predacious mite *Amblyseius hibisci*, a common biological control agent in California. In severe infestations, mite population can reach 1,000 mites per leaf. Its numbers peak with dry summer heat and decline rapidly in the fall, but enough winter survival occurs (eggs overwinter) to repeat the cycle, allowing buildup of adult populations in spring. Gwen is a favorite host, then Hass, Reed, and other cultivars. Certain new UC Riverside selections are comparatively resistant (see table 18.1). Other hosts include citrus fruits (not leaves), deciduous fruits (apricot, peach, nectarine, plum, persimmon), grapes, sumac and liquidambar trees, roses, and acacias. To confirm the identity of persea mite, hold a white sheet of paper horizontally under symptomatic foliage and rap the stem sharply; the mites will be evident on the paper as moving specks. With a hand lens, the eight distinguishing mite legs will be visible, and yellow color should be definitive. The persea mite is gradually coming under good biological control because the population of a predacious mite native to California, *Galendromus annectens*, which can penetrate the persea mite webbing, is increasing. Another predacious mite imported to California by UC scientists for the purpose of controlling persea mite, *Galendromus helveolus*, also holds promise. In the meantime, small and few trees can be helped by water-jet washing, which is more effective if insecticidal soap is added. To minimize initial infection, avoid drought and other stress. Check the UC IPM Avocado Pest Management Guidelines for up-to-date recommendations for control methods approved for home growers.
Scarring on young fruit that starts near the stem end and spreads over entire surface. Feeding on fruit stems causes fruit drop. Pest also feeds on leaves, but defoliation is not primary problem. Darkened, leathery patches on upper leaf surface and random feeding lines on leaf underside. Unlike mites, thrips leave small black fecal pellets.	avocado thrips *(Scirtothrips perseae)*	Similar to citrus thrips *(Scirtothrips citri)*; a very active, oval, yellow insect about $^{1}/_{25}$ in long. Attacks leaves and fruit. New exotic avocado pest first noticed in Jul 1996 in Ventura County. Has spread to many avocado groves statewide. Believed native to Central America. Scarring can be severe, leading to alligator skin. Damage is usually cosmetic. Sanitary precautions recommended, not spraying, because insecticides disrupt beneficial insects. Thrips can fly but are also spread by wind, contaminated clothing, and equipment. UC entomologists are working on introducing new biocontrols.
Fruit and leaves covered with honeydew and sooty mold. Mealybugs present.	mealybugs (*Pseudococcus* or *Planococcus* spp.)	Attack leaves and fruit. Soft, oval, segmented insects, usually whitish, under $^{1}/_{4}$ in long, covered with a mealy wax. They suck plant juices, leading to stunting and, rarely, death. Natural enemies usually control mealybugs, but ants protect them from their natural enemies. If ants are controlled, natural predators such as ladybird beetles will control mealybugs. Handpick small mealybug infestations or daub with rubbing alcohol. For larger infestations, hose off with water or apply insecticidal soap or oil sprays.
Ants present. Ants do not feed on avocado trees but drive away the natural enemies of insect pests of avocados. Argentine worker ants travel in distinct, narrow trails.	Argentine ant *(Iridomyrmex humilis)* Southern fire ant *(Solenopsis xyloni)*	Ants feed on honeydew excreted by scales, mealybugs, and other insect pests and can interrupt biological control of pests. Control ants by denying access to the tree. Apply a band of sticky material around the base of the trunk of mature trees that mechanically blocks ants; prune trees about 2 ft above the ground so ants cannot get into trees without climbing the trunk. Any ant activity is a danger sign. Insecticide or poison baits can reduce ant numbers. Check UC IPM Pest Notes or UC IPM Pest Management Guidelines for products registered for home garden use.

Table 18.5. cont.

PROBLEM DIAGNOSIS FOR AVOCADO

What the problem looks like	Probable cause	Comments
Holes in leaves and fruit. Slimy trails. Diameter of the brown garden snail is about 1 in. Gray garden slug is a snail relative that lacks shell.	brown garden snail *(Helix aspersa)* gray garden slug *(Agriolimax reticulatus)*	Attack leaves and fruit. Most active at night and early morning when ground is damp. Home gardener can handpick; best hunting is after 10 p.m. Or place short, wide boards with cleats at either end to keep the boards about 1 in off the ground; these will be daytime hiding places. Keep snails out of trees by pruning branches up off the ground. Consult UC IPM Pest Notes and UC IPM Avocado Pest Management Guidelines for additional management options.
New leaves have holes and are webbed and rolled together. Caterpillars also feed on developing fruit, scarring it and often rolling and webbing it together with leaves. Caterpillars make shelters by webbing two leaves or a leaf and a fruit. Caterpillar pupates inside fruit. Adult, night-flying, brownish moth emerges. Leaf damage on terminal shoot growth is especially evident for omnivorous looper.	avocadoworms (leafrollers): amorbia moth *(Amorbia essigana)* omnivorous looper *(Sabulodes aegrotata)* orange tortrix *(Argyrotaenia citrana)*	Attack leaves and fruit. Different leafroller pests are often called avocadoworms. Omnivorous looper eats holes in leaves, skeletonizing them so that only the midrib and larger veins remain. Feeds on fruit and causes scarring. Crawls with a looping motion. Usually found near damaged leaves. Can spin a silken thread and hang suspended from it when disturbed. May vary in color from pale green to pink or yellow with stripes or other markings. Grows to $1^1/_2$–2 in long. Amorbia moth caterpillars are yellow-green, about 1 in long. Orange tortrix caterpillars are greenish to bright yellow or pale straw-colored and prefer the top half of trees. Small parasitic wasps and flies usually keep the avocadoworm population low. Certain fungi and viruses are also natural biological controls. The home gardener can destroy avocadoworms by picking them out of their shelters or squashing them in place. Rare, severe outbreaks can be sprayed with *Bacillus thuringiensis* or a chemical insecticide labeled to control this pest on home garden avocados as a last resort.
OTHER PATHOLOGICAL CONDITIONS		
Excess chloride: tip and marginal burn of older leaves, premature defoliation, and sometimes a progressive mottled yellowing behind the burn. Excess sodium: interveinal leaf burn and twig dieback. Other elements rarely in harmful excess.	excess salts (chloride and sodium)	Affects leaves. Salt accumulations are often confused with nutritional deficiencies. Avocados are particularly sensitive to salts, accumulating chlorides and sodium more readily than most other tree crops. Rapid burn at the base or leaf tip followed by defoliation suggests either an excessive fertilizer application or inadequate irrigation. Extra root zone leaching during the summer is indicated.
Pale green to yellow, small leaves with yellow veins (see fig. 18.11); lack of vegetative growth; lower yields; premature defoliation.	nitrogen deficiency	Affects leaves and fruit yield. Apply nitrogen during the first irrigation of each month from Mar–Oct. Young trees need nitrogen applications at different rates than older, mature trees. See the section "Fertilizing" in this chapter and table 18.3.
Light yellow (chlorotic) areas between veins, starting at leaf margins, extending to midrib and base (see fig. 18.12). Small, narrow leaves. Pear-shaped fruit become oval to round, smaller than normal. Terminal growth looks like feather duster. Twig dieback. Defoliation. Reduced yields.	zinc deficiency	Affects leaves, twigs, fruit yield. Can be controlled by applying zinc as a spray to foliage or to the soil. Foliar applications most effective in Jun and Jul. Methods of soil application vary and effectiveness can last longer than foliar sprays. See "Fertilizing" section in this chapter and table 18.4.
Interveinal yellowing on leaves (fig. 18.13). Tip and marginal leaf burn. Defoliation. Twig dieback. Reduced yields.	iron deficiency	Affects leaves and fruit yield. Can occur in high-pH soils containing lime (calcium carbonate) but not common in California. Deficiency accentuated by excess soil moisture. Mexican-race rootstocks are less sensitive. See "Fertilizing" section in this chapter.
Leaves, twigs look water-soaked, then wither, darken. Branches die back, and bark splits in severe cases. Leaves may drop quickly or persist on tree. When fruit freezes, flesh dries out and brownish pits called ice marks may form on skin. Xylem (water-conducting elements) in the fruit turn black.	frost damage	Attacks leaves and fruit first; attacks progressively larger wood after harder frosts. Allow tree to recover before removing frost-killed wood. After new growth appears in early spring, wait for any dieback, then cut back to live wood (identified by a green layer just under the bark). Pruning cuts heal naturally, so no need to paint them. See discussion in "Treatment of Freeze-Damaged Avocado Trees" in this chapter.
Large and small branches blacken, die. Wood peels off in patches. Fruit skin develops tough, brownish spots, and fruit may dry out.	sunburn	Affects trunk, branches, fruit. A problem in hot, sunny areas. Wrap the trunk in white cardboard or use whitewash or flat white latex paint. Maintain adequate nitrogen and water for good foliage. See "Sunburn and Wind Protection" section in this chapter.

Note: For supplemental information and photographs to help diagnose problems, consult the UC IPM Avocado Pest Management Guidelines at the UC IPM website, ipm.ucdavis.edu/PMG/selectnewpest.avocado.html.

the San Joaquin Valley or desert areas. University of California scientists are actively engaged in detecting, testing, and importing predators and parasites of major avocado pests. A number of effective biological control agents are native to California, but if indigenous ones are not available, University of California entomologists and plant pathologists travel to the areas of the world where avocados or their pests are believed to have originated to search for natural predators and parasites. When a particular natural enemy looks promising, specimens are brought back to California with the appropriate permits and placed into quarantine facilities to undergo intensive research. The entomologists and plant pathologists release the imported biological controls into the environment only when research results document their effectiveness and safety.

Chemical control

Pesticides should be used as a last resort. Chemical controls not only kill the target pests but also accelerate development of pesticide resistance. Chemical pesticides may also kill beneficial insects, the biological enemies naturally present or introduced into the garden. Chemical pesticides also raise questions of environmental pollution and health risks. For additional information on general pest management and pesticide use, see chapter 9, "Safe and Sustainable Pest Management."

Treatment of Freeze-Damaged Avocado Trees

Damaging freezes tend to occur in California avocado districts erratically, averaging about one a decade. Certain techniques recommended by the University of California in publications now out of print can hasten tree recovery and maximize desirable growth responses in cold-injured avocados. The techniques are explained in this section.

Determine the extent of damage

Shoot and foliage injury usually becomes visible in a few days. Twigs and small limbs may show little or no sign of cold damage for 2 to 4 weeks. The rate at which freeze damage becomes apparent depends on the prevailing temperatures and humidity and on the condition of growth before and after the freeze period. Except when trees are killed outright, it may be impossible to determine the extent of severe injury for several months or, rarely, even for an entire year following a freeze.

Delay pruning

Corrective pruning should be postponed until the full extent of damage can be determined clearly. Removing deadwood while the branch or shoot is still dying back frequently contributes to further dieback through wound cuts. Postponing pruning gives limbs a chance to recover and eliminates the need for a second pruning to rid the tree of undesirable brush and limb stubs. Experience at the University of California has shown that trees pruned early after a frost or freeze recover more slowly than trees pruned later.

Remove frozen fruit

If the fruit has no value, remove it as soon as possible. The longer fruit remains on the tree, the greater it decreases yield in the succeeding crop.

Treat the trunk and limbs

The degree of injury provides a guide to the type of treatment required.

Light damage. No treatment is necessary when only foliage and small twigs are injured (fig. 18.16). No pruning except "dead brushing" should be done the ensuing season. All live foliage should be retained to nourish the root system and support the developing crop.

Medium damage. If a considerable part of the scion is killed, but the trunk and crown limbs appear sound, the true extent of damage can be determined only after several months. Do not prune until the full extent of the damage is visible. Save as much of the tree's framework as possible. Cut old limbs back below all serious bark injuries; cut back to good, strong shoots. Control the distribution of new

Figure 18.16

Freeze-damaged avocado leaves. *Photo:* T. W. Embleton.

framework branches by selection and light pruning during the summer. After injured branches have been cut back to new leaders, further pruning consists of gradually thinning excessive sprouts over several years. These shoots (suckers) crowd and interfere with the growth and branching of the leaders forming the tree's new framework.

Severe damage. If most of the top and crown limbs are killed, but the trunk shows little injury, no pruning should be done until the full extent of the damage is visible, which will usually become apparent after midsummer. Then, the entire top of the tree should be removed, cutting below all large areas of injured bark. By this time, numerous sprouts from different locations on the trunk will have made considerable growth. From these, the new head of the tree must be formed. Select the uppermost good sprout and cut the old trunk off just above this sprout, sloping the cut downward away from the sprout. Then choose two or three other sprouts properly spaced to form a new head and favor their growth by pinching back sprouts that crowd them. All sprouts should be left until a balance between root and top is established. Unnecessary sprouts should then be removed gradually.

Very severe damage. If the top has been killed and the injury extends well down the trunk but is followed by the appearance of strong sprouts above the bud union, a new trunk and head must be developed. They can be produced from one or more strong shoots originating from above the bud union. With young trees, it is usually best to favor one strong shoot. The top of the tree may then be removed, leaving the old trunk as a support to which this special shoot may be tied. The shoot chosen for development should be favored and forced into growth by pinching back all others.

When the new head has developed to the size of a good 2-year-old orchard tree, remove the old trunk carefully by a cut starting just above the base of the new trunk and sloping downward. The surface of the cut should be allowed to dry. Do not apply wound dressing.

With large trees, recovery is more rapid if several shoots are used to form the new head. There is no objection to avocado trees with multiple trunks. When several shoots are used, it is best to remove the old trunk as soon as the extent of the freeze damage can be determined. Otherwise, new shoots may be damaged excessively by the saw. During the year following the freeze and until the new head is well formed, allow all sprouts to grow. But, as indicated above, control the growth of temporary shoots by pinching them back.

Extreme damage. Usually, trees killed to the bud union should be removed and replaced by new trees. If you must retain such trees, the suggestions for very severely damaged trees should be followed, but shoots selected for forming the new tree must be budded to the desired cultivar as soon as they are large enough to take a bud (about $^1/_4$ to $^3/_8$ inch in diameter). It is best to place the buds at a height of 18 to 24 inches because it allows shoots to grow around the tree base without shading the buds or interfering with their development.

Treatment of damaged bark

Bark on the trunk of freeze-injured young trees may crack and curl. On injured trees of various ages, patches of dead bark may

show up on large limbs or on trunks even where no splitting occurs. When the extent of these injuries becomes clearly visible 2 or 3 months after a freeze, cut out the dead areas of bark smoothly and disinfect and paint the exposed wood.

Protection from sunburn after a freeze

Protection of the trunk and large limbs from sunburn is advisable in warmer areas if regrowth has not occurred before hot weather arrives. Cover only the parts of the trunk and large limbs that "see" south and southwest with whitewash or inexpensive white latex paint.

Irrigation and Fertilization after a Freeze or Frost

Irrigation

Irrigate cautiously after a freeze. When leaves are damaged or destroyed by a freeze, the tree uses less water than under normal conditions until a new crop of leaves has developed. Irrigate only when soil conditions indicate a need. Determine soil moisture content by examining the soil. Irrigations should be less frequent, and smaller amounts of water should be applied until trees have regained their ability to use normal amounts of water. In the case of severely damaged trees, this reduced irrigation requirement may last the entire growing season.

Fertilization

The amount of fertilizer to apply depends largely on the extent of damage. It is best to withhold fertilizer until the extent of damage is determined. Freeze-damaged trees do not respond better if heavily fertilized; in fact, more harm than good may occur. Slightly injured trees will recover most rapidly and will usually set crops in the spring following the freeze. Such trees require normal fertilization.

Severely damaged trees usually put forth a good deal of sucker or shoot growth that will be selected to rebuild the tree. Until the tree regains its full top, an imbalance exists between the root system and top. Trees that have received regular fertilization or are growing on fertile soil have ample nutrients to satisfy their needs the first year following freeze damage. Fertilizer applied before the top has been reestablished may force additional sucker growth that will be difficult and costly to control. Reduce or omit fertilization during the first season on severely damaged trees.

The imbalance between the root system and top, together with vigorous sucker growth following a freeze, often results in micronutrient deficiencies that can retard recovery. Zinc is the element most likely to be deficient in avocados. Zinc deficiency may be corrected by foliar sprays, although recent evidence suggests that foliar applications are less effective than previously thought and soil applications of zinc sulfate might be more effective over the long term. Sometimes iron is also deficient after a freeze. As in citrus, iron deficiency is often the result of excessive soil moisture and can be corrected by reducing irrigation.

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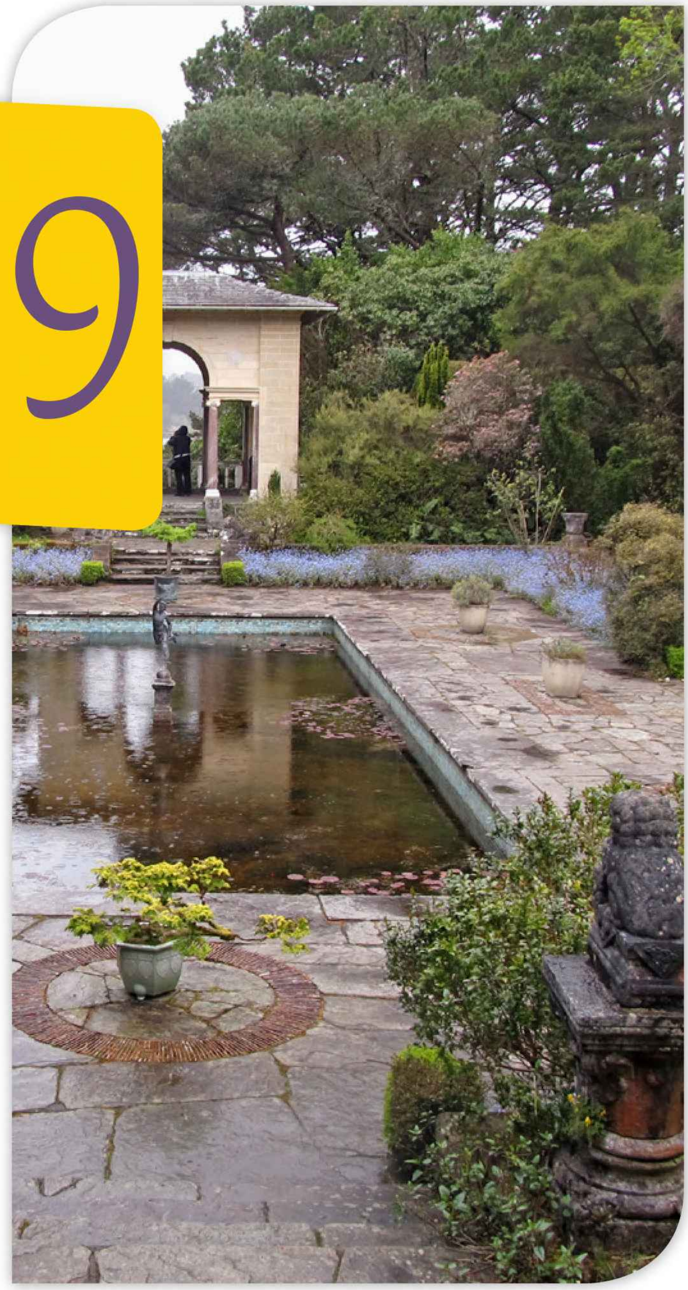
Landscape and Garden Design

19

John F. Karlik



Learning Objectives

Understand basic principles of landscape design.

Understand selected practical considerations of landscape design.

Develop the knowledge to visualize plants (trees, shrubs, turf, and ground covers) as key elements in a comprehensive landscape design plan.

Understand xeriscape concepts.

Understand how to design a simple landscape plan step by step.

Landscape and Garden Design

It is truly an exciting time. Never before has so much been available for your outdoor living space—plants with a seemingly endless assortment of flowers, colors, and textures, and patios with outdoor countertops with built-in grills, fireplaces, and music speakers. Besides concrete, paving materials include travertine, tumbled stone, outdoor tiles, and many other varieties of stones, brick, and pavers.

Landscape design means more than planting trees, shrubs, and turf. It means creating a plan to make outdoor space an additional living space. Landscape design is the art of organizing and improving outdoor spaces through the placement of plant materials, hardscapes, and structures in a functional, attractive relationship that enhances the natural environment. It is a living work of art in which you become part of the entourage. The design should be functional and attractive not only in the eyes of the designer but in the opinion of the people who will use the space and pay for its upkeep. Placing vegetable gardens and orchards appropriately and incorporating edible plants into sections of a landscape enable food production from those areas. Well-designed landscapes and gardens are sustainable; they provide their desired functions indefinitely with minimal negative impact on the environment by needing reduced amounts of water, fertilizer, pesticides, labor, and energy and recycling or reusing green waste.

This chapter considers residential design from an avocational perspective, but the same principles apply to commercial projects and parks. Developing a landscape design includes

- assessing the site's potential
- shaping the design to accommodate desired purposes and uses of the landscape, including food production areas
- shaping the design to make the most of the site's natural features and advantages
- minimizing drawbacks associated with the site
- building fences, walls, patios, decks, or arbors if needed or desired
- installing an efficient, water-conserving irrigation system (for most of California)
- selecting adapted plants, trees, and shrubs that best fit the design in terms of color, texture, form, and fragrance
- adding accent lighting, if appropriate

The final design should implement desired uses of specific areas and consider the movement patterns of the people who use the landscape. The smaller the house, grounds, and budget, the greater the need for careful planning, because every square foot of space and every dollar should produce maximum results. A well-designed and maintained landscape increases curb appeal and resale value of a home, and also increases the home's utility, privacy, aesthetic enjoyment by the occupants, and recreational value.

No landscape is maintenance-free. Some people have a great interest in working with

garden and landscape plants on an ongoing basis, while other people want low maintenance as a primary design goal. An appropriate design considers the local adaptability of plants and the level of maintenance required for various species.

Although it is not necessary to develop the landscape for a new lot or to renovate an existing landscape all at once, an overall plan for the design may ensure that work occurs in stages without retrofitting and that the landscape will be in overall harmony when complete. In other words, plan in advance for complete development or renovation. However, if the implementation of the design is to occur over a longer period, such as years, the owner's desires may change. Therefore, although one may create a longer-term vision to provide guidance, the focus will be on immediate development.

Basic Factors Influencing Landscape Design

A fundamental principle of landscape design is that each planting or construction project should be based on a plan that takes into account the following.

Social information. The designer should strive to understand the desires and needs of the people who will use the landscape and determine how the available outdoor space can be arranged to accommodate them. The designer should ask what they want and what they plan to do outdoors—a questionnaire may be helpful. For residences, analyze family activities and routines and consider outdoor living, relaxing, entertaining, playing, gardening, and household servicing. Make allowances for future changes in the landscape. Small children need open lawn for playing, while avid gardeners need space for growing vegetables and flowers. The original plan for a young family could include open areas in which children and pets can play. As the family reaches its middle years, more extensive and expensive plantings could be put in, and the children's play area could be converted to a lily pond or swimming pool. Singles may desire an extensive area for entertaining or may emphasize low maintenance due to out-of-town job commitments.

Climate. The overall climate, as well as microclimates on the site, influence the choices of suitable planting materials, the design of the irrigation system, and hardscape features.

Site analysis. Consider the nature of the site, its immediate surroundings, views, topography (slopes), ecological conditions, and all natural and human-made objects now existing on the site or planned for the future.

Materials. Determine the available materials, methods of fabrication, and individual preferences. An enormous range of materials exists for pavements, walls, and decks.

Budget. Establish the available resources of money, time, knowledge, and skill. These affect what can be done and by whom.

Ordinances. Investigate city or county regulations. Many communities have setback ordinances that specify fence heights, the permissible height of plants and trees at various distances from the curb, and distances from the lot line or curb that must be maintained when adding structures or features. Fences, decks, lattice work, and other structures may require a building permit. Water-conservation ordinances may also exist that can affect plant selection, placement, or irrigation design. If irrigation is being installed, a backflow preventer is usually mandated. On the other hand, in wet climates restrictions may exist for the allowable fraction of hardscape, since hardscape leads to runoff of precipitation. Corner lots may carry restrictions so that views of drivers are unimpaired. Some cities forbid certain tree species or may limit pruning or removal of existing plants. Restrictions of height or placement of plants, such as around fire hydrants or beneath overhead

power lines, may affect the design. Also, localities may bury utility lines in right-of-way areas and have restrictions on hardscapes or plantings there. In some cases, the locality is required only to restore turf after trenching through a planting bed in the right-of-way. Local ordinances vary greatly, so consult your city or county planning department. In many housing developments in California, a homeowners' association (HOA) is established and usually has an additional set of rules or guidelines, often very specific, regarding alterations to properties within its domain. Whenever changes in a landscape are planned, the rules and guidelines along with the approval process imposed by the HOA should also be considered.

Potential for wildfire. If the property lies in a forested area or is adjacent to naturally occurring open space prone to wildfire, additional landscape design and maintenance factors must be considered to ensure the site is fire safe (see the section "Designing and Maintaining the Landscape for Fire Protection" in chapter 12, "Woody Landscape Plants").

How will climate, availability of landscape materials, and budget affect possible design solutions? Because site analysis, climate, and budgetary constraints (both time and money) are such critical factors in landscape design, they are discussed in detail below.

Site Analysis

Determine the location of property lines to avoid future contention with neighbors or the locality. If unknown, a surveyor could locate them with a boundary survey or by marking the corners. Observe carefully to determine whether site conditions will be a deterrent or whether they can be incorporated into a design plan. The character of the land and its hills, slope, and trees should determine the basic landscape pattern, with consideration to other developed properties in the vicinity so the new landscaping does not appear odd. In developing a design, preserve all the best natural resources on the site, such as mature trees, brooks, ponds, rock outcroppings, good soil, turf, and interesting variations in the terrain. These natural elements affect the ease of construction and landscape possibilities and perhaps can be incorporated into the design so it melds with the natural surroundings. For example, a hilly, wooded lot lends itself to an informal or natural design, with large areas left in their natural state. In such a setting, large trees can be retained and should be protected during site development. Most real estate developers now appreciate the value of trees and attempt to save them when land is graded prior to the construction of houses. Alternatively, it may be possible to relocate trees on-site. Regardless of your affection for trees, it must be understood they do not live forever. Old or improperly located trees should be removed, and new, more suitable specimens should be planted.

Microenvironmental problems on a site—such as low places with cold air drainage, areas with poor soil, or areas with slow rates of water drainage—may require consideration. Exposure to sun and wind at various locations on the property also affects the design. Evaluate soil chemical and physical properties that affect plant growth to determine whether amendment or other action is warranted before establishing landscape and garden areas.

Changes in elevation and resulting views can add interest and variety to the home landscape. Grading of terraces or construction of retaining walls may be necessary to improve and direct water drainage, which should always be away from the home in all directions. Although slopes can be an asset because they provide variation and an opportunity to incorporate focal points and unique views, avoid creating too many steep artificial slopes. Berms need to have gradual slopes to look natural and to facilitate irrigation

and mowing. Terraces and walls should complement the natural setting of the lot. Construction of walls is expensive, so if it is possible to solve problems of slopes or screening with plants, the budget will go further.

Keep good views open and screen out undesirable ones. A shrub or two may provide the necessary screening; if not, a more dense and extensive barrier may be needed. Plantings, fences, and walls can also serve as noise barriers, with plants usually the less-expensive design solution. The principal rooms of the house should look onto the lawn or the garden and view desirable landscape elements or areas, and have other less desirable views obstructed. On small sites, create perspective to enhance the appearance of spaciousness.

In planning the home grounds, give careful consideration to foot traffic patterns, permitting easy access from one area to another and providing sufficient width for passage, usually 5 feet or enough for a garden cart. Traffic may be served by walkways, terraces, or open stretches of lawn. In areas of heavy use, paved surfacing materials are best. Stepping stones are far less expensive than poured surfaces, besides being easy to install, and can be natural stone with ground cover in between.

The design of the walkway to the front door often depends on the location of the front door, where guests' cars will be parked, and the topography of the land. The entry is usually identified as an outcome of the design. If guest parking is at the edge of the street, a relatively straight walk is probably best, if the grade is suitable. Sometimes the topography of the land or the shape of the lot make it desirable to have the entrance walk start at the edge of the property and curve to the front door to take advantage of a gradual grade. If guest parking is on the property, the walk might lead more logically from the guest parking area to the front door. Foot traffic can use the driveway and its aprons in many situations, and the walk to the front door may be parallel to the house and join the driveway rather than extending to the street. This design may also be used if the driveway entrance grade at the street is less steep than the area directly in front of the door, or it might eliminate the need for stairs. If the walk is to be parallel to the house, be sure sufficient space is left for plant material, usually 5 feet or more. If the sidewalk is to extend to the street, be sure to check local zoning to see if a right-of-way is involved. In a cold area, can snow be removed easily?

Climate

Climate can affect the placement of a house on a lot, land use, and the plant materials selected. In planning the landscape, do not fight the climate; capitalize on its advantages. In warm regions, enlarge the outdoor living area. In cold regions, plant so the winter scene can be enjoyed from inside. Needle evergreens and hedges covered with snow are picturesque, and plants with colored bark or persistent berries add interest and attract wildlife.

Because people respond differently to sun and shade, study the amount and location of each on the property. As the angle and location of the sun at sunrise and sunset vary seasonally, sunlight and shade patterns in the landscape also change seasonally, vary throughout the day, and are affected by the location of structures, fences, and trees. Allow for shade from trees and houses on neighboring lots. Plan the location of tree plantings with great care to keep sunny areas for vegetable gardens and orchards, and summer shade for the house and terrace. North-facing slopes may be preferred for orchards in mountain areas so plants do not emerge from dormancy too early, only to be injured by frost. Place deciduous trees on the west and south to provide shade in summer and admit sunlight in winter. Place trees off the corners rather than the sides of the house, where they will accent the house and not block views

or air circulation from windows. However, windbreaks can reduce wind velocity if needed. Modifying climate in the outdoor living area helps extend its period of usefulness.

Budgetary Constraints

Determine an acceptable budget. If the work involves construction, such as walls, decks, or a patio, budget for the construction elements first and use the remainder of the budget for plants. Are construction plans finalized? Will the homeowner do the work, get help from friends, or contract it out? Although construction typically consumes a budget faster than any other item, it may be worthwhile to have key aspects of the design executed by professionals. Mistakes in grading and installation of pavers, for example, are not easy to rectify. Also, is the homeowner equipped to handle certain tasks, like moving large volumes of soil or mulch, excavation, and proper planting of larger trees?

Also consider the level of ongoing expenditure acceptable for maintenance. A low-maintenance plan, which is often the goal of homeowners, may be furthered to a large extent in the planning stage by careful attention to the layout of the site and the selection of plant species. A low-maintenance, cost-effective landscape may be achieved by adopting one or more of the following design strategies:

Use turf effectively for function rather than appearance only. Consider substituting ground covers or natural mulches for turf.

Use paving in heavily traveled areas.

Use brick, concrete, or redwood mow strips for flower beds and shrub borders, and allow enough space around any landscape feature so as to accommodate mowing.

Use hedges, either formal or informal, instead of fences or walls for screening.

Design raised flower and vegetable beds for easy access and weed control.

Install a permanent, automated irrigation system in regions of low rainfall.

Limit the area for annual flower beds, which require recurring expense and work because of their seasonal nature.

Use containerized plants and flowering trees and shrubs for color accents.

Be selective when choosing plant materials. Well-adapted plants typically require less work than marginal selections and are resistant to pests and diseases. Some plants require less pruning than do others but will be equally effective in meeting design objectives.

Keep the design simple, unified in theme, and functional.

Landscape Use Areas and Design Considerations

One approach to landscape design divides available space into three use areas: the public area, the private area, and the service, storage, and work area. Because small lots exist in much of California, these use areas may overlap or be combined. Fruit trees may be used as ornamentals, for example, and front entry areas can be converted into a family patio.

Space dividers may be needed to separate use areas or provide privacy. Dividers also create the background for outdoor living activities and create dominance. The dividers may be constructed features such as fences or walls or be plants used as hedges or borders. However, overuse of dividers makes space seem smaller because it becomes compartmentalized and views are blocked. Plant dividers usually are less costly than constructed features.

Public Area

The public area is the section of the landscape seen by passers-by, generally in front of the house. In traditional American design, the public area is the front yard area facing the street, and the house is to be the focal point of the public view. The landscape in this area should create the

desired first impression of the home. In this approach to design, the lawn is open and shrubs are to the side of the entrance in foundation plantings, giving the appearance of openness and spaciousness. When selecting a planting scheme to define the front entry, consider texture, color, size, and shape so the plants will enhance the welcome for guests. Tall trees in the backyard and medium-sized trees on the sides and in front help accomplish this effect. On small lots, the family may prefer to modify this design approach and choose to enclose the front yard to make it a private area, as discussed below.

Driveways should be safe, functional, and pleasing in appearance. Parking areas and turnabouts should be provided when practical. In general, a hard-surfaced driveway is neater and requires less maintenance than an unpaved drive, and a hard-surface driveway facilitates snow removal. Specialized paver blocks that allow ground cover or turf in the interior are available. Do not plant tall shrubs at a driveway entrance or allow vegetation to grow so tall that it obstructs the view of the street or highway in either direction. Expect a city ordinance for plant height near the street, the driveway, and for corner lots.

The front walkway should be at least 32 inches wide, but ideally it should be 4 to 5 feet wide. Use materials that provide a sure footing in all types of weather. Avoid using materials that are extremely rough or raised, because it is possible to trip or catch a heel on such materials. Design steps so they will be safe, especially in wet or icy weather. Make the treads wider and the risers shorter than the treads and risers used indoors. Install handrails where needed. Curves are friendlier than right-angle turns.

Enclosed Front Yard as a Private Area

Front-yard plantings such as hedges or a screen of trees and shrubs along the street can convert a public area into a private area. Privacy in the front yard may be even more desirable on small lots, if a large window faces the street, or if the front yard is used for outdoor sitting. East and north sides can be especially desirable for afternoon shade. Where space is limited, a tall, attractive fence may provide privacy and be an effective background for shrubs and smaller plants. Check local ordinances before building close to the street. A corollary approach that could be used much more in California is partially enclosing the front entry space. By adding a low wall or fence and screen plantings, the area close to the front door becomes more private and usable. However, care must be taken to ensure that the security of the entry is not compromised by completely screening it from view.

Private or Outdoor Living Area

The private outdoor living area, or outdoor living room, is an important part of the California home, both by tradition and because California's Mediterranean climate is conducive to enjoying the outdoors. This area may contain a patio, deck, or porch for outdoor sitting, entertaining, or dining. A play area may be incorporated, depending on the family's interests and the presence and ages of children. No yard is too small to have a private outdoor sitting area where the homeowner and guests can gather. Access from the house to the outdoor area should be unrestricted. An ideal arrangement is to have the living room or family room open onto a porch or patio and have the kitchen near the outdoor dining area. A more elaborate outdoor plan can include a series of gardens or garden features. Consider the following guidelines when planning private areas.

Terrace, Patio, or Sitting Area

The center of activity for a living area is often a space arranged with outdoor furniture. It may be a porch, deck, or terrace next to the house or a special section of the outdoor living area that might be

under the shade of a large tree or in a shady corner. Flagstone, brick, concrete, textured concrete, and tile on concrete are hardscape materials commonly used for surfacing an outdoor sitting area, but turf can also be used. Wooden decks may be appropriate when slopes or other grade changes occur in the area. The landscape can repeat colors, textures, and materials used in the dwelling.

The size of a paved patio depends on its expected use, the type and amount of furniture desired, and the budget. An area 10 feet by 10 feet is the absolute minimum size for comfortably accommodating four people with a 48-inch diameter table and chairs. An area 12 feet by 12 feet is better. Increase the size if more people must be accommodated regularly or if outdoor cooking and grilling are planned.

Play Area

The play area can be a part of the outdoor living area or separate from it. For very young children, a small fenced area near the kitchen or living area is desirable. This area can have a swing, sandbox, or other play equipment. Yards with a good deal of open lawn space have room for croquet, badminton, impromptu soccer, or a pool. A large tree in the back yard may be ideal for a tree house. A paved driveway or parking area is suitable for skateboarding or basketball for older children, as well as tricycles or roller skating for younger ones. Children's interests change relatively rapidly with age, so the design must be flexible to meet changing recreational needs. Since houses change ownership, the design also ought to allow conversion to fit the interests of singles or older adults. Will areas be accessible to the disabled or those with limited mobility?

Service, Storage, and Work Area

The service, storage, and work area should provide a place for composting, tools, and storage that is convenient for use but screened from the other areas. Also included in this area may be a bed for cut flowers or a vegetable garden. Space often must be provided for garbage cans, air conditioner units, wood storage, compost, propagating structures, a kennel, and so on. Service facilities should usually not be visible from the outdoor living area or from the street. An exception might be an attractive greenhouse or shed designed and constructed so that it blends well into the overall setting, with an interesting composition of plant material around it. Wood or wire fences, brick or masonry walls, and plants alone or in combination are the materials most commonly used to hide or partially screen service areas. To provide unity, consider using the same materials, colors, and textures that are used on the walls of the house.

Year-Round Interest

The plant material selected should offer a variety of interest (color, form, and texture) throughout the year. For winter interest, select shrubs and trees with a winter flowering habit, colorful bark, evergreen foliage, or colorful fruit that also attracts birds. Pools, stone steps, paving, walls, and other architectural features that do not change with the seasons add interesting dimensions to the garden throughout the year. An awning or trellis-type roof can protect visitors from sun. A garden pool or fountain can convey a cooling effect during the hot summer season, as can the use of cool colors, such as blue and violet flowers. Ponds, with or without fish, can add interest but require regular maintenance or they will become unsightly and be sources of odors and pests. In contrast, many plants offer special fragrances that may be enhanced during bloom or warm weather.

Elements and Principles of Landscape Design

Landscape design involves a melding of plant science with art. Like other art forms, landscape design is based on certain elements and principles.

Scale

Scale refers to the proportion between two sets of dimensions. Knowing the eventual or mature size of a plant is critical when locating it near a building such as a house and for correct spacing between plants. Plants that grow too large will overwhelm a building, but small plantings around a large building can be similarly inappropriate. It is essential to know the mature height and spread of a particular plant before using it in a landscape.

Balance

Balance in landscaping refers to the visual weight on either side of a focal point of interest. There are two types of balance, symmetrical and asymmetrical. Symmetrical balance is a formal balance. It has an axis with everything on one side duplicated or mirrored on the other side, as in formal gardens. Asymmetrical balance is an equilibrium or balance achieved by using different objects. For example, if a very large object is on one side of a seesaw, it can be counterbalanced by many smaller objects on the other side. The concept of asymmetrical balance applies to landscaping when there is a large existing tree or shrub, for example. To achieve visual equilibrium, a grouping or cluster of smaller plants may counterbalance the large existing tree or shrub. Balance may also be achieved through the use of color and texture.

Perspective

Because many California lots are small by continental U.S. standards, managing perspective is important. Certain techniques can make spaces seem larger, whereas others can shrink the same area. Usually the design goal is to make an area seem larger. Obstructing the view with overhead tree canopies or structures will close in a space. Similarly, many backyards have turf surrounded by a border of shrubs, which brings the eye to a terminus and confines the space, but a strong accent in the center of a space draws the eye, making the space seem larger. Overuse of dividers partitions space into small boxes and gives a confined or even claustrophobic feeling.

Effective use of color can expand space. Because distant objects appear fine textured and gray, using gray, fine-textured plants across a yard can expand the apparent distance between the viewer and the plant material. Strong colors and coarse textures at the front of a border also tend to visually expand the area. Tapering walkways or plantings toward a vanishing point creates the illusion of distance. To contract space, reverse these concepts and use strong colors and coarse textures to the rear, tapering to softer tones and finer textures at the front. To create perspective with flowers, try rotating a planting bed 90°, making the eye follow outward. Darkness and shadow can appear to increase space at the perimeter. Darkness limits the view but carries an implication of more space beyond. Shadows can be used similarly, for example, to create an illusion of depth by constructing a façade with stepping stones leading behind. If possible, borrow a view that lies beyond the property itself, which means to allow for a line of sight to include objects at a distance. Such borrowed views increase the sense of space within a landscape, especially if such views include expanses of land, water, or mountains.

Unity

To achieve unity, group or arrange different parts of the design to appear as a single unit. Strong, observable lines and the repetition of geometric shapes can contribute significantly to the unity of a landscape design, which should provide a pleasant picture from every angle. Turfgrass and ground covers act as unifying elements, or theme plants such as roses can be used. The colors white and gray can be used as unifiers in a flower bed of mixed colors. A landscape with too many

ideas expressed in a limited area can lack unity. Too many showy plants, plant varieties, lawn accessories, or accent plants with contrasting textures, form, or color violate the principle of unity and can make the landscape seem disjointed. Packing a lot of variability in plant texture, color, and form into a small space to create a sense of movement and energy is possible, but it can work against unity. Try to use fewer plants in an interesting way rather than many plants sporadically, unless your goal is to emulate a botanic garden—and most botanic gardens employ design principles in their arrangements.

Repetition

Repetition is an effective approach for developing unity. Do not confuse repetition in the landscape with monotony. Like a theme repeated in music, repetition is not only more subtle than monotony, but it contributes to interest, unity, and simplicity. For example, consider the use of curves in a landscape design. A curve may begin in bed lines in the front yard, continue in the side yard, and be found once more in the backyard. Alternatively, the repeated use of right angles in a grid design could be used successfully to achieve unity in the landscape. The right angles may begin in the front yard, perhaps on the sidewalk, then be used in the bed lines that go around the property, and be found again in the backyard. By repeating design elements such as bed lines, one can achieve a continuity or flow to the entire landscape. As one further example, specific plant types, for example, roses, may be repeated in the design.

Rhythm

Rhythm refers to the repetition of design elements that directs the eye through the design. It results when the elements appear in regular measures and in a definite direction. Rhythm can be expressed in color as well as form.

Simplicity

Simplicity gives force and impact. Specific application of this "less is more" principle depends greatly on the specific design. Perennial borders and garden areas may be very diverse by nature. However, unless you are creating an arboretum, limit the number of shrub and tree plant species, since there is more visual effect from using fewer species in groupings or massed plantings than installing a few of many species. Multiple varieties of seemingly unrelated plants can appear to be a hodgepodge of plants in disarray. Use plant masses for blocks of color. Use fewer plant species in interesting ways.

Every square foot of a landscape does not have to have something in it. Objects such as birdbaths, statuary, and other ornaments may be overused. Strive to create spaces, not fill them up. Create simple curves and lines that add interest rather than multiple odd-shaped lines that detract from the design and become difficult to irrigate and maintain.

Harmony

Harmony is achieved through a pleasing arrangement of parts. Where more than one plant community or style is used, transitions should be defined. Fortunately, the dominant color of plants is green, and various hues and shades of green seem always to be compatible.

Accent

Accent—also referred to as dominance, focalization, or climax—is important in the total landscape picture. Various parts, if skillfully organized, lead the eye toward the focal point. Accent can also increase the feeling of space. Without accent, a design may be dull or static. Accents may be a garden accessory, plant specimen, plant composition, or a water feature. Emphasis may also be obtained through the use of contrasting textures, color, or form or by highlighting portions of a plant composition with garden lights. Container plants on a patio may fulfill this role.

Boulders are often used as accents, but they should not be overused, and to look natural boulders should be partly buried. Note also that water does not spring from the highest point of land in nature, so recirculating streams should have their source below the grade of other landscape features. Accents should be minority elements of the composition and should create interest via contrasting characteristics. Like sculpture, they may be displayed in at least two ways, hidden in niches within the space dividers or standing free within the area created by the space dividers.

Dominance and Contrast

In any composition, a majority of dominant or repeated characteristics is accented by a minority of contrasting characteristics. The magnitude of contrast refers to the degree of change between visual characteristics, such as plant type, height, form, color, and texture. An example of a plant composition containing contrasting characteristics is described as follows: A space divider is formed by a grouping of arborvitae, upright juniper, or pines, an accent of a staggered planting of crape myrtles (flowering shrub forms) or landscape-type roses, and a transition of a massing of blue fescue or other ornamental grass. Four elements create the contrast between the space dividers and the accents:

Plant types: Needle evergreen and deciduous.

Form: Evergreens are more upright than the shrubs. Ornamental grasses may add a dynamic element by moving in breezes.

Height: The evergreens are taller, the shrubs shorter, and grasses may be short or tall.

Color: Crape myrtles have bright, almost fluorescent, summer flowers. Landscape-type roses can provide color through much of the year. Needle evergreens form a fine-textured green backdrop, while an ornamental grass can provide color near the ground ranging from greens to purple or blue.

Irrigation Design and Xeriscape

Irrigation design involves a separate, complementary design process, and it is vital for most California landscapes. Irrigation design for residential landscapes need not be complicated, and components are commonly available and easy to install. A discussion of irrigation design is outside the scope of this chapter, but for a detailed discussion, see chapter 4, "Water Management."

Xeriscape represents both conceptual and practical approaches to landscape design and was much discussed upon its formulation in the late 1980s and early 1990s. Many of the ideas and principles brought forward at that time have been widely assimilated and are now routinely incorporated into landscape designs. Xeriscape makes good economic and ecological sense, considering California's limited water supply and that about one-fourth of the water consumed in urban areas of the state is used for landscape irrigation. If properly executed, xeriscapes can be less costly but just as beautiful as traditional landscapes. Although plant selection seems to arise first in discussions about water conservation in landscapes, plants themselves do not save water, and a list of water-conserving plants will vary depending on location in California. The goal of all aspects of water-conserving design is to reduce water application to the minimum required for the landscape to provide its intended performance and function. Often this is achieved by simply adjusting the irrigation schedule (frequency and duration of water application). Often, this approach gives the large water savings compared to other landscape modifications.

A registered trademark of the National Xeriscape Council, the term *xeriscape* may

be defined as a landscape that emphasizes water conservation. Derived from the Greek word transliterated as *xeros,* meaning “dry,” xeriscape uses specific landscape design elements and management practices to achieve the goal of water conservation. Xeriscape may also encompass other goals, such as creating habitat, using native plants, responding to the local environment, and using inspiration and materials from the regional landscape. Xeriscape does not preclude using high-water-use plant materials as design elements, but it limits their use in concert with the water conservation objective and stresses their relationship to the overall design. Native plants may be suitable for inclusion in xeriscape designs, but without good irrigation management, native plants do not save water. Also, many natives are not well adapted to irrigated landscapes, even where careful management is practiced. A xeriscape approach may represent an attempt to provide ecological harmony with the surrounding region, and this theme may be expanded to include use of recycled materials, for example. A properly designed and installed xeriscape can reduce net energy consumption by providing shade in summer and allowing the sun to warm dwellings in winter. But these, too, do not of themselves result in water conservation, which must remain the primary goal of a xeriscape approach.

Xeriscapes follow several principles:

Plants are grouped according to their requirements for sun and water; for example, ferns with baby’s tears and Apache plume with rosemary.

Irrigation system zones correspond to plant requirements. For example, shrubs may need water only once per week, but flowers may require water once per day. Separate irrigation lines can be programmed to accommodate differences in frequency and duration.

Irrigation systems emphasize uniformity, especially on turf areas. The emitter types and placements should be appropriate for the type of plant material being irrigated, with drip irrigation a practical alternative in parts of many landscapes.

Turf is used for function more than for appearance. Other plant materials can substitute for turf where frequent foot traffic or play do not occur. As a practical matter, turf is often overirrigated, and reducing the area of turf may help reduce applied water. However, if properly selected and managed, turf can be a water-thrifty plant material. Warm-season grasses are preferred in warmer areas of the state because they offer as much as 50% water savings during the growing season compared to cool-season grasses. However, many homeowners in southern California still choose cool-season grasses because they remain green year-round.

Islands of intensely managed and irrigated plantings are used for accent. A tasteful grouping of plants can make a strong statement with much less water than rambling shrubs or turf.

Plants are selected for climatic conditions to which they are well adapted. Plants from Mediterranean climate regions of the world are suited to many California sites. Native California plants may be used, but not all of them are drought tolerant or grow well in an irrigated landscape. Xeriscape is not limited to natives, and plants requiring high moisture or humidity can be used in suitable microenvironments.

Hardscape elements, such as patios and decks, are used in the landscape design. These enhance the outdoor environment, require no water, and can provide additional color through the use of container plants. Gravel or organic mulches of many colors and textures can be used rather than filling an area with plants.

The landscape is managed to conserve water. Irrigation frequency and duration are adjusted at least four times a year because water-use rates in the landscape vary greatly from season to season in most California locations. During winter months, no irrigation may be needed. Without seasonal

adjustment, landscape areas usually become overirrigated, encouraging weed and disease problems in addition to wasting water.

A good xeriscape is economical. Monthly water bills reflect the water savings that can result when water use is reduced. Appropriate xeriscape plant materials are available at no greater cost than plants that demand more water. Fewer pest problems may occur when plants adapted to the site are grown. Precise application of water limits weed growth and plant diseases.

A good xeriscape combines function and beauty. Crushed gravel from the street to the front door is not California xeriscape. Variations in plant and landscape color, texture, and form are part of a xeriscape design.

Drawing a Landscape Plan

Drawing a landscape plan on paper is highly recommended, and the more detailed the better, because it provides a road map to follow as the project is completed. To begin, a written narrative describing the present site and goals for the new landscape can help you, as the designer, think in specific terms.

Ideas must be gathered for the new landscape. The gathering may occur in many ways, such as noting other landscapes of interest, visiting botanic gardens and arboreta, collecting photos and descriptions found in magazines and on the Internet, and consulting with avocational and professional designers. Visiting nurseries is a good way to see what plants are readily available. Visit display areas done by contractors and take note of landscapes you like while traveling.

An easy way to develop concepts for the use of spaces is to prepare a map of existing features, then sketch ideas on tracing paper overlays. Begin with use areas, or draw ovals to represent concept areas. Although these are necessarily two-dimensional on paper, the areas represent three-dimensional space, and different areas may have a "roof" of tree branches or an architectural feature such as a pergola. Computer software packages are also available to assist in this process. Then, developing a written plan facilitates moving forward in an orderly fashion without wasting resources. The following section provides the information necessary to draw a landscape plan that embodies the elements of good design. Completing these steps enables you to develop a plan that can be implemented over several years as time and money permit. However, as noted earlier, plans can change with time and interest, so concentrate on the part of the design to be implemented presently.

Step 1: Prepare the Base Map

When analyzing the site, prepare a map to scale of the home grounds (fig. 19.1). Use graph paper and let one square equal a given number of feet or draw to scale using a ruler or an architect's scale. The map should include the following elements:

- property lines
- north pointer
- scale used
- contour of the land (use an arrow to show the direction of surface water flow)
- views (point arrows in the direction of each good view)
- undesirable features of home grounds or adjoining property
- house, garage, and other buildings
- immovable features such as rock outcroppings
- existing walks, driveways, and other hardscapes
- existing landscape construction, such as fences, planters, decks, and concrete borders
- existing trees and other plants to be retained—it is almost always easier to retain a plant than establish a new one

Figure 19.1

A sample baseline map. This map is a scale drawing showing the location and orientation of every major plant, structural features, sun and wind patterns, views, slopes, and drainage characteristics, plus other essential data. This base map becomes the foundation on which the final landscape plan is built. *Source:* After Sunset Landscaping Illustrated 1985, p. 35.

- location of septic tank or sewer lines
- location of utility lines, easements, and other HOA or locality restrictions

If you accidentally cut through a utility line with a shovel, you may be required to pay the repair cost, and some repairs, for example, to fiber optic cables, are very expensive. The shallow excavation required for a small wall or installation of shrubs and small trees should not cause contact with buried lines, but larger projects might. In general, always call the utility company and ask for the locator service. In many cities, you must have utilities marked in advance or you'll be subject to a fine if you damage them. Utilities often run in a straight line from the street to their entrance into a building, but there is no guarantee, and they may even circle a house. In older neighborhoods, gas, telephone, and electric lines may not be in a common trench. If utility lines are overhead, limit plant selection to species that will not be too tall at maturity.

Step 2: Decide Usage Options for the Landscape

Consider the usage options most often included in the final development, and make a list that suits your individual needs:

- front lawn area or public area
- outdoor living room or private area
- laundry, service, and storage area
- cooking and eating area
- children's play area
- vegetable garden
- small fruits (berries, grapes, etc.)
- fruit trees
- flower beds
- garden pools
- fountains
- walks
- driveway
- guest parking
- turnabouts
- spa
- swimming pool

Step 3: Place Use Areas on the Map

Place the use areas on the map (fig. 19.2). You may use tracing paper over the base map to sketch ideas. Fit them together with two considerations: traffic flow and use. How will people move from one area to another or from the house to an outside area? Will movement be comfortable? Will the outdoor area be functional in relation to the house? Will it make use of existing features, such as views or changes in the terrain? Try different combinations in relation to rooms of the house, surrounding areas, and potential views.

Step 4: Develop the Landscape Plan

Design driveways, parking areas, walks, and other paved areas. Indicate where plant masses are needed for separating areas, screening undesirable views, providing shade, windbreaks, and beauty (see fig. 19.2). Do not attempt at this point to name the trees and shrubs, but think in terms of how plant masses will serve a purpose and help tie the various areas together into a unified plan. Consider the design elements discussed previously, then consider the mature height, width, and function of the plants.

In preparing the plan, use landscape symbols to indicate trees and shrub masses. Draw symbols to scale to represent the actual amount of space that will be involved. For example, an upright landscape-type rose (shrub rose) variety at maturity will have a spread of approximately 4 feet; so make the scale diameter of the symbol for this plant equal to that size. For many trees and shrubs, their respective diameters will be approximately equal to two-thirds of their heights. Indicate on the map where paving, plants, and structures will be.

Check to see whether the proposed scheme is practical and you can answer the following questions satisfactorily:

Is the driveway design safe, useful, and pleasing? Have a safe entrance, turnabout, and guest parking been provided? Will guests use the front door? Will the proposed drive be too steep?

Are the walks convenient?

Will the view be attractive from the living room, French doors, patio, or dining room?

Has a private, outdoor living area been provided, and is it screened from neighbors, the service area, and other buildings?

Are fruit trees and vegetable gardens placed appropriately and in sunny locations?

Do all the parts fit together into a unified plan?

Have a good setting, background, and privacy been provided?

Have local ordinances and other rules been checked and followed?

Have underground obstacles, such as septic tanks, or overhead obstacles, such as utility lines, been taken into account? Are trees placed accordingly?

Have fire safety guidelines been observed?

Step 5: Create General and Specific Planting Plans

On the map developed in step 4, designate specific plantings. For each tree or shrub mass on the plan, make a set of specifications, which include the following:

Height: low, medium, tall

Form: spreading, upright, columnar, pyramidal, vase shaped, arching, globe

Purpose: shade, background, hedge, screen, accent, mass

Seasonal interest: fruit, flowers, foliage

Type: needle evergreen, broadleaf evergreen, deciduous, palm

Maintenance: insect pests, plant diseases, pruning or trimming, leaf or fruit drop

Cultural needs: shade, sunlight, moisture requirements

Select a plant or group of plants to meet the specifications. Reviewing the information in the next section of this chapter may help. In addition, consult garden books, nursery catalogs, Internet sources, or a local nursery. Become familiar with plant material and discuss your planned needs with nursery staff. Always ask about or research the eventual size of the plant.

Trees are long-lived and relatively inexpensive in initial cost and maintenance compared with lawns, flower beds, and many other features of a design. Shade trees that will become large should be planted first, since they will become dominant design elements and need time for growth. Smaller understory trees should be planted next.

Selecting Plant Materials for a Landscape Design

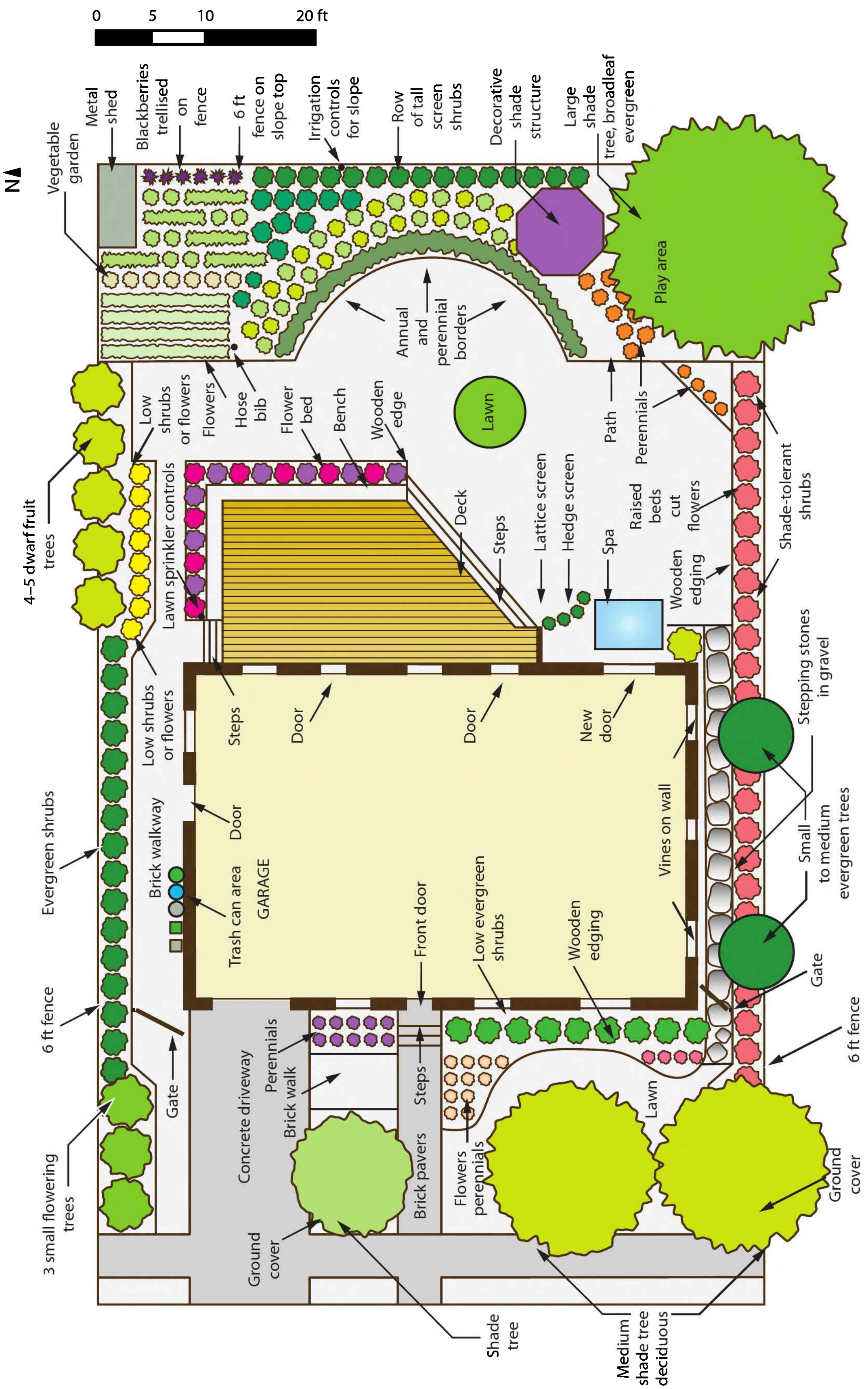
Selecting plant species and varieties is one of the last steps in the design process. Well-chosen plants are necessary to achieve the desired landscape effect, and hundreds of varieties of trees, shrubs, vines, and perennials are available. Plants are not merely ornamental accessories. They make up masses and define space in the yard and, consequently, create the silhouettes that produce the garden design. When selecting plants, consider their texture, color, form, seasonal interest, and overall aesthetic value. Identify plants by scientific name to be sure of accuracy in description and purchase.

Plant adaptation

Adaptation refers to a plant's suitability for use in a particular climate, ability to grow during local winter and summer seasons, longevity or permanence, likely pest problems, and need for extra maintenance. If a desired plant species will not grow well on the site, perhaps you can create an appropriate microclimate that will favor it. Soil and moisture conditions are important components of the plant's environment. For example, some plants can tolerate extremely dry or wet conditions,

Figure 19.2

A sample final plan. Shown is one possible design developed from the base map in figure 19.1. *Source:* After Sunset Landscaping Illustrated 1985, p. 43.



while others cannot. The intensity of sun or degree of shade within a site will dictate where certain species can be located in the landscape. Some plants cannot tolerate full sun, while others require full sun for best display.

Maintenance

In selecting plant materials, consider how much maintenance the plant will require. Choose trees and shrubs that tend to be resistant to diseases and pests. The mature size of a plant should also be considered. A common mistake is selecting plants that soon become too large for their locations.

Plant texture

The texture of plant materials depends on the size, placement, and number of the flowers, leaves, and branches. Plants with large stems or large leaves that are widely spaced have coarse texture; plants with small twigs or small, closely spaced leaves have fine texture. Texture can vary on a seasonal basis, depending on whether the plant is deciduous or evergreen. Strongly contrasting textures can create interesting effects.

Color

Color is perhaps the dominant component of aesthetic appeal, and green is the dominant color of most plant materials. Variety may be obtained by using plants with lighter or darker foliage tones, or variegated leaves. Accents may be introduced by the selection of plants with colored foliage, attractive flowers, or colorful, persistent fruit. Color may have seasonal variation, depending on the plants chosen. Many California landscapes are much brighter than their eastern counterparts because the plant species available, such as bougainvillea, offer vibrant colors and/or repeated bloom throughout the growing season. Good designers create landscapes with attractive color year-round. Planting several shrubs of one species or color rather than a hodgepodge of many shrubs will unify the landscape theme. Blocks of the same plant to create a large mass of color makes a strong design statement.

Color is especially important when planning flower gardens. Mixed colors tend to keep people moving. Massed single colors attract attention and act as focal points or accents. White and gray tend to act as unifiers by tying other colors together. Gray can be used for softening or for accent. Color has significant effect on space perception and perspective, as discussed earlier in this chapter.

Plant form

Trees and shrubs used in landscaping develop many distinct forms. Trees typically grow from 15 to 60 feet or more in height, depending on the species, and commonly have only one main stem or trunk, although some species are available and attractive with multiple trunks, such as birch, chaste tree (*Vitex* sp.), orchid tree, and some palms. Common tree forms with examples include

- round or oval: most shade trees, including alder, maple, oak, Aleppo pine, Italian stone pine (at maturity)
- vase: American elm
- pendulous or weeping: willow, birch, weeping bottlebrush
- pyramidal: spruce, fir, most pines, liquidambar, some ornamental pears
- columnar: Italian cypress

The form of mature trees and shrubs is usually more open and spreading than that of young plants. For example, the head of a young oak tree may be pyramidal in shape, oval during middle age, and irregular during old age. Some common shrub forms and examples include

- low-spreading: prostrate rosemary, creeping junipers
- round or upright: the majority of shrubs
- pyramidal: arborvitae
- columnar: some junipers

Ground covers such as turf, low-spreading shrubs, creeping plants, and prostrate vines are essential materials in landscaping. The principal use of turf is for a

playing surface or an area with foot traffic. Other ground cover plants are commonly used as transitions or in lieu of turf on slopes too rough or steep to mow or under trees where grass will not grow satisfactorily. Ground cover areas may require high maintenance.

Resources

Landscape architects are licensed professionals trained to design commercial and residential landscapes and are qualified to work on public projects such as parks. They charge a fee for design and overseeing the installation of landscaping but do not install it themselves. They can be found by looking for landscape architects in Internet searches, telephone yellow pages, or by contacting the local chapter of the American Society of Landscape Architects (ASLA), asla.org/.

Landscape designers are usually unlicensed and vary in educational background. Some may hold college degrees and be very knowledgeable concerning residential landscaping and construction. Many landscape companies and some retail nurseries have landscape designers on staff. Fee structures vary; design fees may be waived if plants are purchased and installed by the nursery.

Landscape contractors are licensed and trained to install landscapes, plantings, paving, and irrigation systems. They are also trained to interpret and implement the plans of a landscape architect or designer. Some landscape contractors offer limited design services in the total price for materials and installation.

Additional resources include local public gardens and arboreta, which offer garden design ideas such as demonstration gardens. Many excellent books and periodicals are available to supplement the concepts found in this chapter. Internet websites and computer software are increasingly important in this regard.

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Poisonous Plants 20

Judith A. Alsop and John F. Karlik

Learning Objectives

Learn basic principles of toxicology as related to plants.

Develop a general understanding of how to prevent poisoning from common poisonous plants in the home and garden.

Learn how to make a plant identification file.

Learn about the toxins plants contain and the human health symptoms associated with them.

Learn basic information about the common types of skin injury that plants can cause.

Poisonous Plants

This chapter describes typical adverse symptoms and health effects that selected common poisonous plants and plant parts can cause in people. The chapter also includes a table of poisonous plants commonly found around the home and garden and explains how to make a plant identification file. Plants associated with poisonings and other health problems that have been frequently reported throughout the state to the California Poison Control System are listed. Plant species that can cause dermatitis (an inflammation or swelling of the skin) or other form of poisoning, as reported by other reliable sources, are also included.

The table in this chapter lists plants alphabetically by their scientific name to avoid confusion that sometimes occurs with use of common names. We include common names of plants and, for most plants, the following toxicity information: the name of the toxin, which part of the plant contains the toxin, and the human body part or parts that are affected by the toxin. Note that the chapter does not include all known poisonous plants that could be found in California gardens or landscapes, only those commonly found in these settings and that are toxic in some way to people.

Sources used in compiling this information include California Poison Control Center data, textbooks, scientific journal articles, and field guides. A bibliography at the end of the chapter provides reference materials.

Poisonous Landscape and Garden Plants and Symptoms Resulting from Poisoning

Many hundreds of species of poisonous plants grow in the United States. Some of the most beautiful trees, shrubs, vegetables, and vines are poisonous. They provide shade, colorful flowers, or food, but parts of the plant (sap, leaves, seed, flowers, stems) may also contain toxic compounds. Some poisonous plants have substances that irritate the skin or mouth and cause stomach upset, while others can cause vomiting or diarrhea. Skin rashes are one of the most common health complaints that arise from handling poisonous plants, but fatalities can occur when toxin-containing plants or plant parts are ingested. Some of the very toxic plants also taste very bitter, possibly reducing the risk of poisoning, but there are no simple tests to identify which plants are poisonous. Poisonous plants or their toxicants may be inadvertently introduced at home via medicinal teas and homemade medicines. Heating or cooking does not necessarily reduce or eliminate the toxins in plants or mushrooms.

Although many plants contain significant amounts of natural toxins, these plants need not always be eliminated from the home or garden. It does mean that homeowners should be prepared to identify all plants on their property. Homeowners should also know whether plants found in their landscape could be toxic in some way and, ideally, should have some knowledge of the symptoms associated with these poisonous plants.

Each year about 70,000 people call poison control centers across the United States about plant and mushroom exposures, and one in four plant calls to poison centers nationwide involves an exposure to a plant of unknown identity. Without knowing the name of the plant, shrub, weed, or tree, poison center staff cannot provide accurate information regarding toxicity.

Children are the most frequent victims of plant poisoning, making up two-thirds of calls to poison centers regarding plant exposures. Thus, it is critical to watch children when they are playing or otherwise have access to any poisonous plants in the home, garden, or other public areas where plants are grown (relatives' homes, parks, school yards, church, etc.). It is critical to teach children that plants are beautiful but should not be eaten, and some should not be touched, either. Children should be told not to eat garden seeds, berries, mushrooms, or leaves from any plant at any time, even if others dare them to do so. They should also not suck on the flowers, unless an adult verifies that the plant is not toxic.

Do not assume a plant is nontoxic because birds or animals eat it without harmful effects. Eating a small amount of a poisonous plant may not be a problem, but large or repeated small doses could cause toxic symptoms. The signs of poisoning may not appear for many hours after tasting, chewing, or swallowing poisonous plant parts.

What to Do If Plant Poisoning Is Suspected

If you suspect that someone has been poisoned by a plant, telephone your doctor or the Poison Control Center at 1-800-222-1222. The information you provide about the plant that was consumed will help a health professional determine the proper treatment. If you are advised to go to the hospital, take a sample of the plant with you, if possible.

Eating any wild mushrooms collected outdoors is potentially dangerous. Call the Poison Control Center at 1-800-222-1222 even if you only suspect that someone has eaten a mushroom. Never just wait and see. Don't guess that everything is okay because no symptoms have developed. After a poisoning, symptoms may not appear until many hours later.

Preventing Plant Poisoning

Plant poisoning can be prevented. If you employ practical prevention measures, such as storing bulbs and seeds where children cannot reach them, keeping house plants out of reach, and teaching children about poisonous plants, you can prevent most problems. Do not use twigs as sticks for roasting hot dogs or marshmallows unless you are sure that the plant from which they were taken is safe. For example, oleanders are common landscape shrubs that contain a poisonous principle, making their leaves and stems very toxic, so oleander wood should never be used as barbequing skewers. If you develop the plant identification file described below, you will know which plants are poisonous.

Some of the most poisonous plants also can be sources of valuable pharmaceuticals. For example, digitalis, which is derived from the leaves and seeds of foxglove *(Digitalis purpurea)* was originally used to strengthen the heartbeat of an ill person. However, self-treatment with plant parts or homemade teas from plants can be fatal and must be strongly discouraged. Herbal remedies may have undesirable side effects and may contain varying concentrations of bioactive compounds.

Keeping Plant Identification Records

Create a hard copy or a computer file list called "Plants: Identification." Keep it with your important papers or store it in your computer. Enter the telephone number of the Poison Control Center (1-800-222-1222) in your file and in the front cover of your telephone book.

Use the scientific or botanical name to record plant identity. Common names may refer to several different plants that may not be related.

Keep a copy of the identification tags from the plants you buy and put them directly into your plant identification file. Keep the original identifying tag attached to the plant for quick reference. Make a diagram of your landscape with its plants identified.

To identify plants already in your home or garden, consult resources such as the *Sunset Western Garden Book*, contact a California Certified Nursery Professional (CCNPro) at a local retail nursery or garden center, or contact your local UC Cooperative Extension county office for help in identifying your plants. Bringing the plant or as many plant parts as possible (not just one leaf or one berry) to a retail nursery or a UC Cooperative Extension office is perhaps the best way to identify a plant. Calling over the phone and trying to describe a plant can result in serious and potentially life-threatening errors in identification.

Taking a photo of the entire plant and a close-up of leaves and/or berries or flower with a digital camera or cell phone camera and e-mailing the picture to a plant expert may be another alternative if you cannot take the actual plant in for identification.

Once the plants have been identified, take photographs of them. Use a flash both indoors and out to fill in shadows. The best outdoor light for taking identification photographs occurs early in the morning, late in the afternoon, or on cloudy days. Use an indelible marker to write the names of the plants on the back of printed photos or create a digital photo album with the plant name placed in the caption for each photo. Keep the photos in your plant identification file. Let relatives, babysitters, and pet sitters know about the file, its location, and how to access it.

Plants and Their Toxic Principles

Toxicology is the study of poisons and how they affect living organisms. People and animals are continually exposed to toxic principles in the environment, which include specific chemical elements, chemical compounds, and radiation. As a basic principle of toxicology, it is the dose that often determines whether toxicity will occur. The toxic principles of plants are usually chemical compounds manufactured by and found within the plant. Whether or not a specific chemical compound is toxic is affected by several factors, such as the following:

- potency of the toxicant (activity per gram, often considered relative to the mass, or weight, of a person or animal)
- concentration of the toxicant in the plant part
- route of exposure (oral, dermal, inhalation)
- dose (amount) received
- amount absorbed
- overall sensitivity of the person to the toxicant
- mode of action of the toxicant
- organ or system affected within the person

A plant species may contain several types of chemically unrelated toxic compounds, often referred to as toxic principles. Many of these poisonous compounds have been studied and identified, while others are not well understood. Although it may be known that ingestion of a specific plant genus or species results in injury, a specific chemical compound

may not have been identified. Taxonomic relationships of plants may be helpful in evaluating the potential for toxicity. However, even among plants of the same species, variability in chemical concentration can occur.

The concentration of plant toxins can vary in different parts of the plant. Some plants concentrate toxic compounds in the seed but not the leaves; in others, unripe fruit may be toxic but not ripened fruit; in others, such as oleander *(Nerium oleander)*, all plant parts are toxic.

Geographic location, time of year, and growing conditions of the plant may influence the concentration of toxic compounds. For example, nitrate toxicity is affected by plant water stress.

In addition, distinguish between hazard and risk. Hazard is the nature of an event, such as plant poisoning. Risk is the likelihood of such an event, which may be affected by where the plant is located, the height of the plant, access of people to the plant, ages of people, and so forth.

This chapter focuses on the potential of plant toxicity to humans. Livestock injury and mortality from ingestion of poisonous plants is well documented, with an extensive research base. Some of the plants listed in this chapter are quite toxic to animals. Animal genera and species vary in their sensitivity to the respective poisonous components. However, a discussion of plant toxicity to livestock or other domestic animals is outside the scope of this book.

Toxins Found in Plants

Toxins found in plants may be described in several ways. In some cases the poisonous component has been identified and its molecular formula and structure determined; for these, the chemical may be named. Some toxicants may be classified based on their structure or presence of a functional group, for example, steroid, pyridine, or glycoside. Some compounds may be described in terms of the organ system affected, for example, cardiac. A more specific description of compounds may not be available (e.g., a resin), or the biochemical mechanism of a particular poisonous component in causing toxicity may not be known, although the organ system affected may be known.

Toxins classified based on the nature of a chemical reaction or similarity to a chemical class include the following:

Alkaloids, which are alkali-like. They can form salts upon reaction with acids and act as bases in reactions. They usually have a bitter taste, as do true alkalis.

Glycosides, which yield one or more sugars if the molecule is cleaved. The toxic principle is the nonsugar portion of the molecule.

Oxalates, which are salts of oxalic acid. The oxalate ion is responsible for the toxic effects.

Saponins, which are large molecules that form a soap-like froth when shaken in water.

Toxins classified based on the effect on an organ system include the following:

Cardiac glycoside, which affects the heart.

Cyanogenic glycoside, which yields hydrocyanic acid (hydrogen cyanide), which prevents respiration at the cellular level.

Toxins classified based on the specific chemical include the following:

Ricin, of castor bean, is well studied, a protein of more than 100 amino acids.

Oleandrin, found in oleander, is a modified steroid.

Cochicine is also well studied, since it affects a later stage of cell division (microtubule retraction) and is used in laboratories to interfere with DNA replication.

In some cases, a toxic agent may be classified into more than one category. For example, oleandrin can be also considered

to fall within the broader group of cardiac glycosides. Solanine, found in the nightshade family, sometimes including potatoes, is a combination of solanose (a sugar) and solanidine (the active principle). Since it contains a sugar, solanine can be considered a glycoside. In terms of its physical properties, solanine may be considered a saponin. The active principle solanidine is a modified steroid that behaves as an alkaloid, so it could be called an alkaloid steroid.

Plants That Injure the Skin

Mechanical Injury

Mechanical injury is perhaps the most common injury associated with plants. When thorns, needles, spines, or other plant parts become embedded in the skin, chronic irritation may result if the material is not removed quickly. A simple way to remove the hairlike thorns common on cacti is to apply a thin layer of white (Elmer's) glue over the thorns. Allow the glue to dry. Then apply a piece of masking or duct tape over the glue. Remove the thorns by quickly peeling off the tape-glue plaster.

Thorns that embed deeply in the skin near joints may cause painful, inflamed joints similar to chronic arthritis. If they embed near bones, they may cause a reaction in which the body walls off the thorn in solid, tough tissue that may resemble a tumor. This reaction may also occur even if the thorn is not near bone, but it is less common.

If a thorn embeds deep in a joint (knuckle, wrist, elbow, knee, toe, etc.) a severe infection may develop that requires hospitalization. A stab wound to a joint is an emergency situation and should not be ignored.

Plants commonly associated with mechanical injury include

- agave, including century plant *(Agave americana)*
- blackberry (*Rubus* spp.)
- cacti (family Cactaceae)
- citrus (*Citrus* spp.)
- *Melaleuca* spp. (some)
- palms (some)
- pyracantha (*Pyracantha* spp.)
- roses (*Rosa* spp.)

Primary Irritant or Contact Dermatitis

The most common injury following a skin exposure to a toxic plant is dermatitis, an inflammation or swelling of the skin accompanied by redness, itching, and tenderness to touch. Irritant dermatitis can be caused by caustic or irritating substances produced by plants that come in contact with or injure the skin. This results in nonallergic, inflammatory skin reactions, or rashes. No one is safe from an irritant: if enough of the material contacts the skin, a rash will develop.

Irritant dermatitis is a very common complaint with plants in the arum family (Araceae), which includes such common house plants as dieffenbachia, arrowhead vine, peace lily, philodendron, and pothos. All of these plants have special cells that contain calcium oxalate, or oxalic acid, crystals. When a leaf is brushed, handled, broken, bent, or chewed, it ejects the crystals. These crystals embed themselves in the skin or mouth or whatever surface is in contact with the plant. Oxalic acid is extremely irritating. Members of the spurge family (Euphorbiaceae), such as spurge and to a much lesser extent poinsettia, are also commonly associated with dermatitis.

Many other plants are commonly associated with causing irritant dermatitis. Keep in mind that many of these plants can cause more serious symptoms than just dermatitis, especially when ingested.

Plants that cause irritant dermatitis include

- arum family (dieffenbachias, philodendrons, pothos, caladium)
- bulbs of many kinds (tulips, daffodils, hyacinths, buttercups, narcissus)
- carrot *(Daucus carota)*
- castor beans (*Ricinus* spp.) (very toxic if ingested)
- celery *(Apium graveolens)*
- century plant *(Agave parryi)*
- cowslip (*Primula* spp.)
- Euphorbia family, including pencil tree *(Euphorbia tirucalli)*, poinsettia *(E. pulcherrima)*, and spurges (*Euphorbia* spp.)
- *Ficus* spp. (fig, rubber tree)
- foxglove (*Digitalis* spp.) (very toxic if ingested)
- milkweed (*Asclepias* spp.) (very toxic if ingested)
- mushrooms (various species)
- parsley (*Petroselinum* spp.)
- parsnip *(Pastinaca sativa)*
- tomato (stems and leaves)*(Lycopersicon esculentum)*
- trees including alder (*Alnus* spp.), ash (*Fraxinus* spp.), beech (*Fagus* spp.), birch (*Betula* spp.), cedar (*Cedrus* spp.), elm (*Ulmus* spp.), maple (*Acer* spp.), mesquite (*Prosopis* spp.), oak (*Quercus* spp.), pine (*Pinus* spp.), poplar (*Populus* spp.), and spruce (*Picea* spp.)
- turnip *(Brassica rapa)*

Allergic Contact Dermatitis

Allergic contact dermatitis (ACD) differs from irritant contact dermatitis in that only sensitized (allergic) individuals react to contact with the plant material, which is known as the allergen. It is rare for allergic individuals to react the first time they are exposed to an allergen. The first encounter sensitizes the allergic individual. Usually, the next encounter with the allergen stimulates the allergic response. ACD usually results in redness, itching, and the development of small blisters, but it may become so severe that large fluid-filled blisters form. As with irritant dermatitis, ACD injury is limited to the skin area exposed to the plant material.

Often, people exposed to plant allergens will use topical anesthetics (containing benzocaine, dibucaine, lidocaine, or other chemicals ending in the "-caine" suffix) and will develop an ACD plant reaction to the medication in addition to the primary ACD reaction.

Allergic persons may experience reactions to topical antibiotics (neomycin and bacitracin), topical antihistamines (diphenhydramine), and topical mercury compounds (mercurochrome and merthiolate). Nickel is the most common metallic sensitizer; it causes more ACD problems than all other metals combined (Zamula 1990). A person who develops a rash needs to consider exposure to plants, medications, nickel, and anything new to which he or she might have recently been exposed.

Many plants are commonly associated with ACD. Keep in mind that many of these plants cause other more dangerous symptoms than just allergic dermatitis, especially when ingested. Plants that cause allergic contact dermatitis include

- aster (*Aster* spp.)
- birch (*Betula* spp.) (pollen can cross-sensitize people to apples, carrots, and celery)
- bulbs (*Narcissus* spp., including daffodil and narcissus)
- carrots *(Daucus carota)*
- castor beans (*Ricinus* spp.) (very toxic if ingested)
- cayenne peppers (*Capsicum* spp.)
- cedar trees (*Cedrus* spp.)
- celery *(Apium graveolens)*
- chrysanthemums (*Chrysanthemum* spp.)
- citrus (*Citrus* spp.)
- English ivy *(Hedera helix)*
- garlic *(Allium sativum)*
- geraniums (*Geranium* spp.)

ginger (*Zingiber* spp.)

ginkgo (female trees only; fruit of *Ginkgo biloba*)

laurel (sweet bay) *(Laurus nobilis)*

lichens (various species)

liverwort (*Hepatica* spp.)

magnolia (*Magnolia* spp.)

oleander *(Nerium oleander)* (very toxic if ingested)

onion (*Allium* spp.)

philodendrons (*Philodendron* spp.)

primrose (*Primula* spp.)

sawdust from various trees, including laurel (also known as sweet bay or bay leaf) *(Laurus nobilis)*, Brazilian pepper *(Schinus terebinthifolius)*, and silk oak *(Grevillea robusta)*

smoke tree *(Cotinus coggygria)*

Toxicodendron spp. (poison oak, poison ivy, poison sumac) (strong local skin reactions)

Photosensitization Dermatitis

Photosensitization dermatitis is a special case of ACD in which sunlight is required to cause injury. In livestock animals, photosensitivity results from the animals grazing on plants that produce chemicals capable of injuring the skin after being exposed to sunlight. In humans, photosensitization dermatitis is more common from chronic skin exposure to plants or plant parts that sensitize the skin to sunlight. After recovery from photosensitization dermatitis, the skin will be darkened permanently.

Plants associated with human photosensitization dermatitis reactions include

anise (*Pimpinella* spp.)

buttercup (*Ranunculus* spp.)

carrot *(Daucus carota)*

celery (with pink rot) *(Apium graveolens)*

dill *(Anethum graveolens)*

fig (*Ficus* spp.)

Klamath weed (*Hypericum* spp.)

lime (and other citrus rinds) (*Citrus* spp.)

mustard seed (*Brassica* spp.)

parsley (*Petroselinum* spp.)

parsnips *(Pastinaca sativa)*

Persian limes (*Citrus* spp.)

Plants That Are Poisonous If Ingested

Remember that many plants in the house and outdoors can be poisonous to humans and animals. If you even suspect a possible exposure, call your physician or the Poison Control Center. The poison center is available free of charge 24 hours a day at 1-800-222-1222. Don't guess; be sure!

Flowers, Perennials, and Holiday Plants That Contain Toxins

Numerous poisonous flowering plants occur worldwide, and some are found in California homes and gardens (table 20.1). Some of these plants, such as foxglove, have been used for centuries in both medicine and mayhem.

Calla lily (*Zantedeschia* spp.)

Calla lilies are elegant flowering plants that grow in the home garden and wild in the countryside. They are popular choices for bridal bouquets and cut flower arrangements. White calla lilies are the most common color, but they are also grown in green, pink, purple, yellow, and orange varieties. The calla lily grows from a rhizome and produces large green leaves. The flower blooms from the top of a thick stem and is spathe shaped. All parts of the plant contain oxalate crystals. Biting into the plant or chewing plant parts causes irritation, burning, and stinging of the mouth, lips, and tongue. Vomiting and drooling may be seen. Intense pain in the mouth usually prevents ingestion of large amounts of the plant.

Easter lily *(Lilium longiflorum)*

Easter lilies are cultivated as potted plants at Easter time. They have large, attractive, fragrant, funnel-shaped white flowers. Easter lilies are not toxic to humans but are very toxic to cats.

Table 20.1.

SELECTED POISONOUS PLANTS OF THE HOME, LANDSCAPE, AND GARDEN FOUND IN CALIFORNIA

Scientific name	Common name	Toxic part[1]	Toxin[2]	Effect[3]
Acokanthera spp.	bushman's poison	WP	—	very toxic
Aconitum spp.	monkshood (aconite)	WP (UP, SD)	A, CT	GI, severe NS
Adonis spp.	pheasant's eye	LF, ST	G	GI
Aesculus spp.	buckeye, horsechestnut	SD, LF, FL	G	GI, NS
Agave americana	century plant	LF, SP	O, OX	GI, SK
Aglaonema spp.	chinese evergreen	AG	OX	GI, SK
Ailanthus altissima	tree-of-heaven	LF, FL	—	SK
Amaryllis belladonna	belladonna lily (naked lady, pink lady, resurrection lily)	UP	A	NS, RP
Anemone tuberosa (A. patens)	anemone (pasque flower)	WP, FL	—	GI, SK
Anthurium spp.	flaming flower	WP	OX	GI, SK
Apium graveolens[4]	celery	AG, SP	FU	severe SK
Arceuthobium spp.	dwarf mistletoe	WP	P	CV, GI
Arisaema triphyllum	jack-in-the-pulpit	WP	OX	GI, SK
Artemisia spp.	wormwood, sagebrush, mugwort	LF	O	GI, NS, SK
Arum maculatum	lords and ladies	WP	OX	GI, SK
Asclepias spp.[5]	milkweed	WP	A, G, R	severe NS
Asparagus densiflorus 'Myers' and 'Sprengeri'; *A. setaceus*	asparagus fern	AG	—	SK
Asparagus officinalis (garden asparagus)	asparagus	AG	—	SK
Baileya multiradiata	desert marigold	WP	—	—
Brassica nigra	mustard	UP, SD	—	SK
Brugmansia spp.	angel's trumpet	WP	A	severe NS
Buxus microphylla, B. sempervirens	boxwood	FL, ST (WP)	A, R, O	GI
Caesalpinia spp. (*Poinciana* spp.)	bird of paradise (red, yellow, Mexican)	SD	UNK	GI
Caladium bicolor	caladium	WP	OX	GI, SK
Cephalanthus occidentalis	buttonbush	LF	G	—
Cestrum spp.	cestrum (night-blooming jessamine)	LF, ST	—	—
Chamaedorea spp.	bamboo palm, parlor palm	FR	OX	SK
Chenopodium album	lambsquarters (goosefoot)	WP	N, OX	BL, GI, SK
Chrysanthemum spp.	chrysanthemum	AG	PN	SK
Clematis spp.	clematis (virgin's bower)	WP	G, O	GI, SK
Clematis vitalba	traveler's joy	LF	G, O	GI, SK
Colchicum autumnale	autumn crocus (meadow saffron, naked ladies)	WP	COL	GI
Colocasia antiquorum	elephant's ear	WP	OX	GI, SK
Conium maculatum	poison hemlock	WP	A	NS, RP
Convallaria majalis	lily-of-the-valley	WP	CARD	severe CV
Corynocarpus laevigata	kara nut; laurel	SD	—	—
Crinum asisticum	crinum lily	UP	A	GI
Crotalaria spp.	canary bird bush	WP	A	—

Table 20.1. cont.

SELECTED POISONOUS PLANTS OF THE HOME, LANDSCAPE, AND GARDEN FOUND IN CALIFORNIA

Scientific name	Common name	Toxic part[1]	Toxin[2]	Effect[3]
Cyclamen purpurascens	cyclamen	WP	G	GI
Cypripedium spp.	lady's slipper orchid	LF, ST	—	SK
Daphne spp.	daphne	ST	—	very toxic
Datura stramonium[6]	jimsonweed	WP	A	severe NS
Daucus carota	carrot	SP	FU	SK
Delphinium spp.	delphinium (larkspur)	WP, SC	A, CT	GI, NS
Delphinium virescens	larkspur	WP	A, CT	GI, NS
Dianthus spp.	carnation	AG	—	GI, SK
Dicentra spp.	bleeding heart	LF, UP	A	NS
Dieffenbachia spp.	dumbcane	WP	OX	GI, SK
Digitalis purpurea	foxglove	WP	CARD	severe CV
Duranta repens	golden dewdrop	FR, LF	G	GI
Echium vulgare	blue weed	LF, ST	—	SK
Epipremnum aureum, Scindapsis aureus	pothos	LF	OX	GI, SK
Eriobotrya japonica	loquat	LF, SD	CG	ETS
Eschscholzia californica (E. mexicana)	California poppy	WP	A, G	NS
Euonymus europaea, E. spp.	euonymus, European burning bush	LF, FR	—	—
Eupatorium regosum	white snakeroot	LF, ST	—	—
Euphorbia lactea, E. grandicornis	candelabra cactus	FL, ST, SP	PH	GI, SK
Euphorbia milii	crown of thorns	WP	PH	GI, SK
Euphorbia pulcherrima	poinsettia	SP	PH	SK, GI
Euphorbia spp.	euphorbia (snow-on-the-mountain, crown of thorns)	SP	—	SK
Euphorbia spp.	spurge (ground, spotted, thyme leaved)	SP	PH	SK
Ficus spp.	fig, rubber tree	SP	OX	GI, SK
Gelsemium sempervirens	yellow jessamine	WP	A	GI, SK, RP
Ginkgo biloba (female plants)	ginkgo, maidenhair tree	FR	—	SK
Gloriosa spp.	climbing lily	WP	A	NS
Hedera helix	English ivy	FR, LF	G	GI, NS, SK
Helenium spp.	sneezeweed	WP	G	GI
Helleborus spp.	hellebore (Christmas rose)	WP	G	GI, SK
Heteromeles arbutifolia	toyon, Christmas berry	LF	—	—
Hippeastrum spp.	amaryllis	UP	—	GI
Hyacinthus orientalis	hyacinth	UP	OX	GI, SK
Hydrangea spp.	hydrangea	WP	CG	ETS, GI
Hymenocallis aviaricana	spider lily	UP	A	GI
Hypericum perforatum[7]	St. John's wort	WP	—	SK
Ilex aquifolium	English holly	FR	GI, NS	—
Ilex spp.	holly	FR	G	GI
Impatiens spp.	impatiens	WP	—	
Ipomea alba	moonflower	SD	—	—
Ipomea tricolor	morningglory	SD	NAR	NS
Iris spp.	iris	LF, UP	CG	ETS
Juglans spp.	walnut	SP	—	SK

Table 20.1. cont.

SELECTED POISONOUS PLANTS OF THE HOME, LANDSCAPE, AND GARDEN FOUND IN CALIFORNIA

Scientific name	Common name	Toxic part[1]	Toxin[2]	Effect[3]
Kalmia latifolia	mountain laurel	LF	—	—
Laburnum anagyroides	golden chain tree	WP	A	GI, severe NS, RP
Lantana camara	lantana	FR	—	GI
Lantana spp.	lantana	WP	—	GI, CV
Lathyrus odoratus spp.	sweet pea	WP	P	NS
Laurus nobilis	sweet bay, bay leaf	LF, ST, FR	O	SK
Ligustrum spp.	privet	LF, FR	A, G	GI
Linum usitatissimum	flax (requires large quantity to create toxicity)	WP, esp. SD	N, cyanide	RP
Lobelia spp.	lobelia	WP	—	SK
Lupinus spp.	lupine	WP	A	severe NS, RP
Lycopersicon esculentum	tomato	LF, ST	A, S	GI ?
Macadamia ternifolia	Queensland nut (not the edible species)	LF	CG	ETS
Maclura pomifera	osage orange	SP	—	SK
Malus domestica	apple	SD, LF	CG	ETS
Manihot esculenta	cassava	UP (uncooked)	CG	ETS
Melia azedarach	chinaberry, umbrella tree	FR	complex	GI, NS
Mirabilis jalapa	four-o'-clock (marvel of Peru)	SD	weak A	GI
Monstera deliciosa	monstera (split-leaf philodendron)	FR, LF	OX	GI, SK
Morus spp.	mulberry	FR (unripe), SP	unknown	mild GI
Myoporum laetum	ngaio (myoporum)	LF	—	very toxic
Narcissus spp.	narcissus, daffodil	UP	OX	mild GI
Narcissus tazetta	narcissus	UP	—	GI, NS, SK
Nerium oleander	oleander	WP	CARD	CV, GI
Nicotiana spp.	nicotiana	WP	A	NS
Ornithogalum spp.	star-of-Bethlehem	WP	CARD, strong CT	CV, GI
Oxalis spp.	oxalis (Bermuda buttercup)	WP	OX	GI, SK
Papaver somniferum	opium poppy	FR	NAR	NS, GI
Parthenocissus quinquefolia	Virginia creeper (American ivy)	FR, LF	OX	GI, SK
Philodendron spp.	philodendron	WP	OX	GI, SK
Phoradendron spp.	American mistletoe, Christmas mistletoe	WP, esp. FR	P	CV, GI
Pittosporum spp.	pittosporum	LF, ST, FR	—	very toxic
Primula spp.	primrose	WP	—	SK
Prunus amara	bitter almond (not the almond of commerce, which is *P. dulcis*)	FR	CG	ETS
Prunus spp.	apricot, cherry, peach, plum	SD, LF, ST	CG	ETS
Pteridium aquilinum	bracken fern	WP	CG	BL, CAR
Pyracantha spp.	firethorn, pyracantha	FR	—	severe SK
Pyrus spp.	pear	SD (large quantity)	CG	ETS
Quercus spp.	oak	FR, LF	tannin	mild GI
Ranunculus spp.	buttercup	WP	G	GI, SK; seed very toxic

Table 20.1. cont.

SELECTED POISONOUS PLANTS OF THE HOME, LANDSCAPE, AND GARDEN FOUND IN CALIFORNIA

Scientific name	Common name	Toxic part[1]	Toxin[2]	Effect[3]
Rhamnus spp.	buckthorn (coffeeberry, pigeonberry)	LF, ST, FR, SP	—	SK, GI (laxative)
Rheum spp.[8]	rhubarb	LF (blade, not petiole)	OX	GI, SK
Rhododendron spp.	azalea and rhododendron	WP	CT, R	CV, GI
Ricinus communis	castor bean	young LF, esp. SD	RS, LF, SD	CV, severe GI, RP, SK
Robinia pseudoacacia	black locust	ST, SD, LF	G	GI, BL
Rumex spp.	dock	LF	OX	GI, SK
Sambucus spp.	elderberry	FR (raw)	A, CG	GI
Saponaria vaccaria	cow cockle	SD	G	GI
Schefflera spp.	schefflera	AG	OX	GI, SK
Senecio jacobaea	common ragwort	WP	A	—
Senecio mikanioides	German ivy	LF, ST	—	—
Sesbania punicea (Daubentonia punicea)	rattlebox, scarlet wisteria	SD	—	—
Solandra spp.	cup-of-gold vine	LF, FL	—	—
Solanum dulcamara	bittersweet	LF, FR	A	NS
Solanum melongena	eggplant	LF, ST	A	GI
Solanum pseudocapsicum	Jerusalem cherry (winter or Christmas cherry)	WP	strong CARD	CV
Solanum spp.[9]	nightshade	LF, FR, WP, esp. FR	A, CARD	NS, CV
Solanum tuberosum	potato	G	A	LV
Spathiphyllum spp.	peace lily	WP	OX	GI, SK
Syngonium podophyllum	arrowhead vine, nephthytis	WP	OX	GI, SK
Tanacetum vulgare	common tansy	LF	—	—
Taxus spp.	yew	WP (SD)	strong A	NS, GI
Thevetia peruviana	yellow oleander	WP	—	—
Toxicodendron diversilobum (Rhus diversiloba)	poison oak	WP	O	severe SK
Toxicodendron (Rhus) rydbergii	poison ivy	WP	O	severe SK
Tulipa spp.	tulip	UP	OX	GI, SK
Urtica dioica	stinging nettle	LF, ST	M	SK severe
Veratrum californicum	false hellebore (skunk cabbage)	WP	A	NS, RP
Veronica virginica	culvers root	UP	—	—
Viscum album	European mistletoe, Christmas mistletoe	WP	P	CV, GI
Wisteria spp.	wisteria	WP, esp. SD	G	strong GI
Zantedeschia spp.	calla, calla lily, arum lily	WP	OX	GI, SK
Zephyranthes spp.	zephyr lily	LF, UP	OX	GI

Notes

—: Information on the toxic part, toxin, or effect could not be found or is unknown.

[1]Toxic parts: AG = aboveground parts; FL = flower; FR = fruit; G = green parts; LF = leaf; SD = seed; SP = sap; ST = stem; UP = underground parts; WP = whole plant.

[2]Toxins: A = alkaloid; CARD = cardiac glycoside; CG = cyanogenic glycoside; COL = colchicine; CT = cardiotoxin; FU = furocoumarin; G = glycoside; M = multiple agents; NAR = narcotic; N = nitrate; O = oil; OX = oxalate; PH = phorbol; P = proteins or amino acids; R = resin; RS = ricin; S = saponin; UNK = unknown.

[3]Effect (organ system[s] affected): BL = blood; CAR = carcinogen; CV = cardiovascular; ETS = cell respiration, electron transport system; GI = gastrointestinal; LV = liver; NS = nervous system; RP = respiratory paralysis; SK = skin irritation.

[4]Toxins are produced almost solely by *Apium graveolens* (celery) infected by pink rot fungi.

[5]All *Asclepias* spp. should be considered poisonous, even those cultivated as ornamentals.

[6]*Datura* spp. in general are toxic.

[7]*Hypericum perforatum* is not the commonly used species in California, which is *Hypericum calycinum*.

[8]Because of the lethal amounts of oxalic acids concentrated in its leaf blade, rhubarb (*Rheum* spp.) is considered one of the most dangerous of all plants in a garden.

[9]All ornamental and wild *Solanum* spp. (nightshade) should be considered poisonous.

Foxglove *(Digitalis purpurea)*
Foxglove is a biennial garden herb that grows 1 to 5 feet tall. It has tubular purple, pink, yellow, or white-lavender flowers with rosette-like leaves. Foxglove is the original source of the drug digitalis, which is used medicinally to stimulate a weaken d heart. Eating fresh or dried leaves and swallowing seed can cause poisoning and death. Signs of poisoning include nausea, vomiting, abdominal pain, diarrhea, headache, drowsiness, dizziness, mental confusion, blurred vision, trembling, irregular heartbeat, slowed heart rate, heart block, and death.

Holly (*Ilex* spp.)
An evergreen shrub with sharply toothed leaves and red berries, holly is widely planted in California. Some holly species are used for Christmas decorations. This shrub is considered potentially dangerous to children because they may eat the berries in large quantities. The sharp, spiny leaves can cause mechanical injury in the mouth if eaten. The plant, and especially the berries, contain ilicin. Signs of poisoning include nausea, vomiting, diarrhea, and drowsiness. Symptoms depend on the amount of berries eaten. Lethal cases have been reported in the past, but recent poison center experience indicates that nausea, vomiting, and diarrhea are much more common. Serious symptoms occur in ingestions of very large numbers of berries only.

Hydrangea *(Hydrangea macrophylla)*
Hydrangeas are beautiful flowering deciduous shrubs found outdoors and also as potted flowering plants with large clusters of bold pink, white, or blue dense, globe-shaped flowers. There are numerous cultivated varieties and wild species. The leaves and buds contain hydrangin, a cyanogenic glycoside with the potential to produce cyanide. However, in the few reported poisonings, the symptoms were limited to nausea, vomiting, and diarrhea. Weakness, light-headedness, and shortness of breath may also occur. Allergic contact dermatitis has been reported in a few cases. Animal poisonings have been reported in older literature, but no recent cases were found.

Lady's slipper orchid (*Cypripedium* spp.)
This beautiful orchid has blooms in shades of white, yellow, crimson pink, or purplish brown. The flowers have a pouch-like lip. The toxin, an irritant substance, possibly a fatty acid, contained in the stems and leaves frequently causes contact dermatitis. Depending on the susceptibility of the individual, skin irritation may be minor, or it may be a painful inflammation with blisters that lasts for days or weeks.

Lantana (*Lantana* spp.)
Lantana camara is a mounding perennial shrub, 1 to 3 feet high and 2 to 6 feet in diameter. The stems are sometimes prickly. The serrated leaves have a rough upper surface and are in groups of threes. Flower color varies according to the cultivar, including creamy white, yellow and pink, and orange and scarlet. Flowers are borne in clusters. The fruit is a berry that is green to blue before turning black. It is about 1/4 inch in diameter and contains a single, hard seed. The unripe green berries contain the highest concentration of the atropine-like toxin lantadene. Symptoms of poisoning from eating unripe berries appear within about 6 hours of consuming poisonous plant parts. Symptoms include vomiting, diarrhea, dilated pupils, weakness, incoordination, lethargy, slow and labored breathing, and coma. Chewing on or eating a leaf is not known to cause symptoms in humans. However, the rough surface of the leaves can cause dermatitis. Trailing lantana *(L. montevidensis)* has a purple flower and a lower growth habit. Berries are not associated with this plant, although the stems and leaves may be irritating.

Lily-of-the-valley *(Convallaria majalis)*
Lily-of-the-valley is a sweet, fragrant, spring-blooming perennial herb with small, bell-shaped, white flowers. It is a

good ground cover in partial shade areas. The fruit is a red-orange berry. Leaves, flowers, and berries are toxic and contain the cardiac glycosides convallarin and convallamarin. Signs of poisoning include nausea, vomiting, stomach pain, dizziness, fatigue, headache, drowsiness, irregular heartbeat, irregular pulse, and heart block. The toxic reaction is similar to that of digitalis found in foxglove.

Mistletoes

The term *mistletoe* is used for at least three groups of plants: dwarf mistletoe, European mistletoe, and American mistletoe. The latter two are leafy mistletoes, whereas dwarf mistletoes are parasites of conifers, have plant forms unlike the leafy mistletoes, and are not used for holiday decorations; exposure to dwarf mistletoe would not be likely.

In California, American mistletoe, *Phoradendron* spp., is found on deciduous trees, such as native oaks and ash, as a woody semiparasitic evergreen shrub with greenish branches forming a dense bushy growth 1 to 6 feet in diameter. Leaves and stems are leathery in texture, about $^1/_2$ to $1^1/_2$ inches long. The flowers are small and inconspicuous. The fruit, produced in autumn, is a small whitish berry with a viscid pulp. Ingestion of *Phoradendron* plant parts usually results in symptoms lasting less than 6 hours. Ingesting a few of the berries would be expected to cause mild nausea, vomiting, and possibly diarrhea. Ingesting concentrated extracts of the plant or berries may produce serious poisonings with symptoms of vomiting, diarrhea, abdominal pain, confusion, drowsiness, incoordination, hallucinations, seizures, and increased rate of breathing. Information on human overdose is limited. Most data are from animal experiments in which large doses of the mistletoe extracts were injected. The toxicity of mistletoe is further confused because of the similarity of the *Phoradendron* and *Viscum* mistletoe genera.

European mistletoe refers primarily to *Viscum album*, which in California is found only in Sonoma County. European mistletoe is a green-yellow aerial parasitic evergreen shrub. The berries are white and sticky with one seed. European mistletoe grows on various trees but prefers apple, oak, and pear. It forms a drooping bush 2 to 5 feet in diameter. It has been used for Christmas decorations. The fresh bark and leaves of European mistletoe have a characteristic disagreeable odor and a nauseating, acrid, bitter taste. European mistletoe is considered more toxic than American mistletoe. Ingesting a few of the berries would be expected to cause mild nausea, vomiting, and possibly diarrhea. Ingesting large amounts of plant parts or drinking concentrated extracts or teas of the plant or berries may produce serious poisonings. Symptoms could include vomiting, diarrhea, abdominal pain, confusion, drowsiness, incoordination, hallucinations, seizures, and increased rate of breathing. Information on human overdose is limited. Most data are from animal experimentation where large doses of the mistletoe extracts were injected. The toxicity of mistletoe is further confused because of the similarity of the *Phoradendron* and the *Viscum* mistletoe genera.

Poinsettia *(Euphorbia pulcherrima)*

Poinsettias are widely cultivated as festive holiday potted plants at the Christmas season. While the red poinsettia is most common, poinsettias come in various shades of red, pink, and yellow. Poinsettias may cause mild skin irritation and nausea or vomiting if large amounts are ingested. Poison control centers consider poinsettias safe plants to have in the household over the holidays. The myth that poinsettias are deadly results from a historical case of one death reported to be due to ingestion of a poinsettia in 1918, and there is much doubt that the plant involved was actually a poinsettia.

Tobacco, ornamental (*Nicotiana* spp.)

There are many species of nicotiana plants, commonly called tobacco plants. *Nicotiana tabacum* is cultivated for leaves

used to make cigarettes and cigars, but it is not commonly found in California. Other nicotianas are cultivated as ornamental garden plants. All can cause nicotine poisoning if ingested. Symptoms can include rapid and spontaneous vomiting and increased heart rate and blood pressure, followed by a slowed heart rate and decreased blood pressure. Other symptoms include headache, confusion, tremors, hallucinations, weakness, paralysis, coma, respiratory failure, and death.

Weeds, Wildflowers, and Miscellaneous Plants That Contain Toxins

Of all plant categories covered in this chapter, weeds are responsible for most of the deaths resulting from poisonous plant ingestion, especially among livestock. Most weeds have a variety of defense mechanisms, including very poisonous natural toxins, many of which are alkaloids (table 20.1). Alkaloids can be excreted in milk. Poisonings have occurred when livestock owners have consumed milk from livestock that have grazed on weeds containing alkaloids, such as lupine (*Lupinus* spp.).

Artemisia, sagebrush, and wormwood (*Artemisia* spp.)

Wormwood has been used for centuries as a moth repellent, general pesticide, and a tea or spray to repel slugs and snails. Before its toxicity was known, it was used as an internal deworming medicine for people and animals. It is a herbaceous perennial plant with a hard, woody rhizome. The plant grows to about 2 to 3 feet tall. The leaves are greenish gray above and white below, bearing tiny oil-producing glands. Some *Artemisia* spp. are considered to be toxic if ingested in large amounts. Many of these plants produce undesirable flavors in milk due to the volatile oils they produce. If leaf parts are crushed, the volatile oils release a distinctive sagebrush-like scent. Symptoms can include headache, dizziness, vomiting, diarrhea, sweating, and vision distortion. Ingestions of large amounts may cause seizures, coma, and respiratory failure. Dermatitis may also occur.

Castor bean *(Ricinus communis)*

The castor bean plant is native to the tropics but is also found along California roadsides as well as planted in gardens for its large, striking appearance. It is a herbaceous annual that can reach nearly 15 feet tall. The leaves are glossy and often red or bronze tinted when young. Flowers appear in clusters at the end of the main stem in late summer. The fruit consists of an oblong, spiny pod that usually contains three seed. The seed are oval and light brown, mottled or streaked with light and dark brown, and resemble pinto beans. The seed are attractive to children. The inner seed part is white and oily. The entire plant, but especially the seed, contains ricin, an extraordinarily potent and toxic toxalbumin. The severity of symptoms depends on the degree the seed are chewed. If seed are swallowed whole or without damaging the seed coat, toxicity is less likely. Toxalbumins initially cause severe irritation of the throat or stomach, similar to alkaline caustic burns. Symptoms include bloody vomiting and diarrhea, abdominal pain, and sloughing of the stomach and bowel tissues, along with fever, drowsiness, and lowered blood pressure. Symptoms are usually seen 2 to 6 hours after exposure. Two to five days after exposure, damage to the liver, central nervous system, kidney, and adrenal glands can occur. Death in children may result from ingestion of only two or three seed. Castor beans may cause severe allergic reactions in hypersensitive individuals.

Jimsonweed (*Datura* spp.)

This plant is known by several names, including jimsonweed, thornapple, stinkweed, locoweed, hell's bells, and devil's trumpet. Jimsonweed is found in foothills, dry pastures, along roadsides, and in vacant city lots nationwide. It grows to about 2 feet high and has trumpet-like

white or pale violet flowers with coarsely toothed leaves. Egg-shaped fruit about the size of a large walnut are covered with spines. The plant has a strong, offensive odor. Contact with the leaves and flowers can cause dermatitis. Consuming large amounts can be fatal. Powerful alkaloids of atropine, hyoscyamine, and scopolamine are found throughout the entire plant, and all parts are toxic. Making a tea from the plant has resulted in poisoning. Signs of poisoning include thirst, dry mouth, blurred vision, dilated pupils, increased heart rate, dry hot skin, fever, inability to urinate, constipation, delirium, and hallucinations, and these unpleasant symptoms can last for many days. Death may result.

Larkspur (*Delphinium* spp.)
More than 250 species of annual larkspur and perennial delphinium exist worldwide. Leaves are deeply lobed, and flowers are borne on long terminal stalks. Many species are weedy, but others are cultivated. Leaves and seed may cause contact dermatitis. If planted in the garden, larkspur should be out of the reach of small children because all species are toxic. The plant contains diterpenoid alkaloids, specifically delphinine. Toxicity decreases as the plants age. Eating young leaves before the flowers appear can cause poisoning. The seed are also poisonous. Signs of poisoning include upset stomach, abdominal cramps, tremors, weakness, paralysis, and death. Eating larkspur is a major cause of cattle death.

Milkweed (*Asclepias* spp.)
Milkweed is a coarse, erect plant with a milky juice, hence its name. Milkweed is the sole food source of the monarch butterfly larva, and the plant is often used in butterfly gardening. The veins on the leaves are thick and yellowish. Flowers are white, greenish white, pink, orange, or rose colored, and they grow in closely rounded clusters. The fruit is a seedpod that is large, flat, and rough textured. Each pod contains many seed and has a tuft of long, silky hairs. All parts of the plant are toxic, with highest concentrations in the stem and leaves. The plant is most toxic just before maturity, and toxicity decreases upon drying. Some of the more toxic species retain enough of the toxic principle to be dangerous when mixed with hay. The toxic chemicals present in milkweed, asclepiadin and asclepion, are members of a group of cardiac glycosides called cardenolides. Symptoms usually appear a few hours after ingestion and can include stomach upset, loss of appetite, diarrhea, weakness, seizures in short and repeated intervals, labored breathing, rapid and weak pulse, sweating, dilated pupils, and kidney or liver degeneration. Death follows a comatose period and respiratory paralysis within one to several days after ingestion. Milkweed also contains some latex that can cause mild dermatitis.

Monkshood (*Aconitum* spp.)
Monkshood is found along creeks, in woods, and on mountain slopes. Its showy flowers are blue, purple, white, or yellow and have a characteristic helmet shape. The plant's tuberous root has been mistaken for a wild horseradish, sometimes with fatal results. The toxic juice in the flowers, leaves, stems, roots, and black seed contains aconitine alkaloids. Poisoning from monkshood can cause some unique symptoms. Chewing the plants can cause a burning sensation in the mouth, followed by swelling or numbness of lips and tongue. Eating the plant can result in violent vomiting, diarrhea, and tingling of the fingers and toes, followed by sweating and chills, a pins-and-needles sensation on the skin, a feeling of intense cold and pain, heart rhythm irregularities, respiratory failure, paralysis, and death. Symptoms can last for several days.

Nightshades (*Solanum* spp.)
The genus *Solanum* includes a number of introduced weeds naturalized in waste places, cultivated fields, and around homes. Nightshade has white flowers with large yellow anthers. The fruit are dull

black when fully ripe. The toxic principle, solanine, is contained in the whole plant of all *Solanum* spp. Unripe nightshade berries reportedly contain the highest concentration of solanine, whereas there is less in ripe fruit. The numerous species of nightshade, including *S. carolinense*, *S. dulcamara*, *S. gracile*, and *S. nigrum*, have common names including black nightshade, blue nightshade, common nightshade, deadly nightshade, silverleaf nightshade, woody nightshade, climbing nightshade, and poisonous nightshade. Signs of poisoning include nausea, vomiting, diarrhea, drooling, fever, dilated pupils, headache, weakness, sweating, muscle cramps, shortness of breath, and changes in heart rate. Death is possible but rare.

Poison hemlock *(Conium maculatum)*
The toxicity of poison hemlock has been known since antiquity and, based on symptoms, it is thought to be the hemlock responsible for the death of Socrates. Poison hemlock is an extremely poisonous plant that grows along ditches, fences, and roadsides. Ingestion of poison hemlock has resulted in numerous deaths. Poison hemlock is a coarse, erect, biennial, herbaceous plant, 4 to 10 feet tall. The stems are hollow, jointed, and have many branches. The stems usually have purple spots or lines. The whole plant, especially when young, resembles carrot or parsnip plants. The taproot is white, usually unbranched, and resembles a carrot or parsnip root. Leaves resemble parsley or a fern leaf. Deaths have resulted when poison hemlock has been mistakenly ingested, by people thinking the plant was wild carrot, wild parsnip, or wild parsley. Fresh leaves have a nauseating taste, and when bruised they emit a characteristic parsnip-like odor described as mousy or musty. The flowers are small, white, and borne in flat-topped clusters. The fruit is a small capsule containing the seed, which are grayish brown, oval, and flat. The whole plant contains the toxin coniine. Initial symptoms can include a burning sensation in the throat, profuse drooling, thirst, double vision, dilated pupils, nausea, vomiting, abdominal pain, headache, dizziness, lethargy, confusion, respiratory depression, kidney failure, intense muscle pain followed by muscle paralysis, seizures, coma, and death. Death is usually rapid and due to paralysis of the muscles used in breathing. Throughout this ordeal, victims may not lose consciousness. Rubbing plant parts on the skin may produce a burning sensation followed by numbness and/or dermatitis.

Poison oak *(Toxicodendron diversiloba* or *Rhus diversilobum)*
"Leaves of three, let it be!" Poison oak can be found on the Pacific Coast from 5,000 feet down to sea level. The leaves have a characteristic three leaflets (but may have up to five leaflets), and are shiny on top and dull on the underside. In the autumn the leaves turn a deep shade of red before falling. The toxic principle, the oil urushiol, is found in all parts (roots, stems, leaves, flowers, and fruit) and can cause severe dermatitis. Urushiol is not volatile, so the plant must be touched if dermatitis is to occur. Urushiol binds to skin proteins within about a minute, so immediate washing is necessary if it is to be removed. A common route of exposure is via tools or clothing that have touched the poison oak plant, since the oil adheres to these surfaces and retains its toxicity. Onset of symptoms can range from 8 hours to 2 weeks. Severity of the reaction depends on the patient's degree of skin sensitivity, the amount of contact, and areas of skin exposed. Repeated exposure seems to increase sensitivity. Face and genitals are more sensitive than other areas of skin to the toxicant. Skin eruptions are characterized by streaks of redness and blisters in groups or lines that may be accompanied by significant swelling, especially if contact is on the face. The fluid exudate from blisters cannot cause additional blisters to form. Dermatitis can affect large areas of skin and in severe cases requires hospitalization, including immunosuppressant

medications. Skin exposure to poison oak does not result in systemic toxicity. However, ingestion of poison oak is a different story and may lead to skin flushing, itching and burning of the lips, mouth, and anus as the plant passes through the body. Headache, abdominal pain, diarrhea, nausea, and vomiting were reported in patients ingesting poison oak. Also, breathing of soot particles from plants as a result of brush fires or forest fires is dangerous, since urushiol bound to inhaled particulates can cause swelling in lungs, requiring hospitalization.

Stinging nettles *(Urtica dioica)*

Stinging nettles are a bothersome annual or perennial herb that can grow up to 6 feet tall. The stems and coarsely toothed leaves are covered with stinging hairs. The flowers are small, greenish, without petals, and growing in loose clusters. None of the nettles are considered to have toxic properties when ingested, but they can cause severe reactions on contact with skin. More than two dozen chemical agents have been isolated from nettles. Symptoms from skin exposure include intense burning, itching, inflammation, and blisters. Symptom severity usually depends on individual sensitivity and the amount of contacted skin surface. Each stinging hair has a bladder-like base filled with the irritant chemical; upon skin contact with the plant hair, the chemical is pressed into the skin from the bladder, injecting the chemical irritant into the skin. The stinging sensation can be severe and may last up to 12 hours.

Water hemlock *(Cicuta douglasii)*

Water hemlock is found along streams and in swamps, damp meadows, and wetlands. It is a perennial that grows from a thick root and is usually 2 to 4 feet tall. Leaflets range from 1 to 4 inches long. The flowers have small, white petals. It rarely grows above 8,500 feet in elevation. All parts are toxic, but the toxicity is greater in the lower part of the stems and roots. The toxic agent is cicutoxin. The rootstock of the water hemlock plant is a single large root that has been mistaken for parsnip, turnip, and wild carrot. Humans have been poisoned by ingesting the underground parts, having mistaken them for edible wild vegetables. A mouthful could be fatal. Water hemlock can be differentiated from wild vegetables by cutting open its thick rootstock. The root of water hemlock has numerous hollow chambers rather than being solid. Toxicity of roots is not lost upon drying. Roots exposed by plowing fields can be a source of livestock poisoning. Symptoms in humans are many and include nausea, vomiting, diarrhea, convulsions, tremors, extreme stomach pain, drowsiness, dilated pupils, fever, increased heart rate, hallucinations, altered level of consciousness, pins-and-needles sensation, amnesia, kidney failure, heart failure, respiratory depression, and death. Seizures can occur within 5 minutes to 2 hours after ingestion. Death may occur from 15 minutes after ingestion to 8 hours.

Vegetables That Contain Natural Toxins

Common vegetables can produce natural toxins that cause skin rashes, upset stomachs, and, rarely, death (see table 20.1). Two very potent toxins are produced by diseased celery and potatoes (see below). Diseased celery produces a toxin activated by sunlight that can cause a severe skin rash known as celery picker's disease.

Asparagus *(Asparagus officinalis)*

Asparagus is a perennial vegetable, and, after flowering, red berries form on feathery branches. Prolonged, repeated handling of asparagus can cause dermatitis. Steroidal saponins are most likely involved in poisonings, but little is known of their effect. Asparagin and the glucoside vanillin have been identified, but the sensitizing agent has not been found. Signs of poisoning vary from mildly reddened skin to painful swelling accompanied by blisters and itching. Severity depends on the amount of exposure and individual sensitivity.

Eggplant *(Solanum melongena)*
While the fruiting body of the eggplant is safe to eat, the green parts—leaves and stems—contain solanine. Signs of poisoning include nausea, vomiting, prolonged diarrhea, drooling, drowsiness, fever, and weakness.

Potato *(Solanum tuberosum)*
Potato tubers are very nourishing, but eating potato leaves, sprouts, vines, and potatoes with green skin caused by exposure to sunlight has caused poisonings. Remove green spots and sprouts before cooking potatoes because heat does not destroy the toxin solanine associated with green parts of the plant. Signs of poisoning include nausea, vomiting, prolonged diarrhea, drooling, drowsiness, weakness, and fever.

Rhubarb *(Rheum* spp.)
Rhubarb leaves are large, heart shaped, dark green, and about 1 to $1^1/_2$ feet long, with wavy edges. The leaf stems or stalks (petioles) are edible, and are used in pies, sauces, and jam. They are long, red to greenish red, depending on the variety. Flowers are small, greenish, whitish, or reddish, and borne in clusters. The leaf blades contain oxalates and possibly other toxins. Poisoning has resulted when people have cooked rhubarb leaves and served them as greens. Possible symptoms include vomiting, diarrhea, weakness, drowsiness, reduced blood clotting, and kidney and liver damage. The leaf blade is reported to have caused dermatitis.

Tomato *(Lycopersicon esculentum)*
The annual garden tomato is related to the deadly nightshade. For centuries, certain Europeans thought that tomato fruit were poisonous and cultivated the plant only as an ornamental. Although fresh tomatoes are harmless, controversy still exists regarding the toxicity of green leaves and vines (stems), which may contain the toxicant solanine. Signs of poisoning include nausea, vomiting, diarrhea, drooling, drowsiness, fever, and weakness. Until more research is done, caution should be used before deciding whether tomato vines and green leaves are safe for human consumption.

House Plants That Contain Toxins

Numerous house plants belonging to the Araceae (arum family) contain various forms of oxalic acid, often found as sharp, needlelike oxalate crystals in plant tissues (see table 20.1). Crushing, breaking, or chewing the plant causes the release, or "firing," of these crystals. The crystals are extremely irritating and you may have noticed your fingers or arms itching after handling one of these plants. Fortunately, if a child or pet bites into a leaf, the irritation in and around the mouth and throat, while painful, is usually not severe enough to require emergency medical attention. Common house plants that contain oxalates are listed below. Different parts of different house plants have different degrees of toxicity.

Arrowhead vine, nephthytis, and trileaf wonder *(Syngonium podophyllum)*
The arrowhead vine is an easy-to-grow cultivated house plant. Identification may be difficult, since the leaves of the juvenile plant are arrowhead shaped, whereas the leaves of the adult are usually three-parted, each part with 3 to 13 segments. The juvenile plant is most often seen in cultivation. Leaves are green or sometimes variegated with silver, cream white, or yellow. Flowers are spathe shaped and green, but not often seen. The fruit is a brown berry that is fused together in clusters. The entire plant contains toxic calcium oxalate crystals. Signs of poisoning include burning and stinging of the lips, mouth, and tongue immediately after chewing on plant parts. Vomiting and drooling may be seen. In severe cases, swelling can make talking and breathing difficult. Intense pain in the mouth usually prevents ingestion of large amounts of the plant.

Caladium (*Caladium* spp.)
Cultivated for its beautiful leaves, caladium is used extensively as a house plant or as a summer bedding plant. Leaves are colored with bands and blotches of white, silver, red, pink, rose, and green. A tuberous-rooted perennial with white flowers, caladiums have a bitter juice containing toxic calcium oxalate crystals. Signs of poisoning include burning and stinging of the lips, mouth, and tongue immediately after chewing on plant parts. Vomiting and drooling may be seen. In severe cases, swelling can make talking and breathing difficult. Intense pain in the mouth usually prevents ingestion of large amounts of the plant.

Dumbcane (*Dieffenbachia* spp.)
These evergreen foliage plants are favorite indoor ornamentals for homes, apartments, and businesses. They have large leaves with variegations in pattern and color, including white, pale cream, lighter green, and bluish. The commonly cultivated species, *Dieffenbachia picta* and *D. seguine*, are called dumbcane because chewing on the leaves may paralyze the vocal chords and tongue and lead to temporary loss of speech. Leaves and stems are poisonous because they contain calcium oxalate needlelike crystals. Signs of poisoning include intense burning and irritation of lips, mouth, and tongue after biting or chewing the stem or leaves. Swelling may interfere with breathing and cause choking. Death can occur if the swelling of the tongue blocks the air passage to the throat. Intense pain in the mouth usually prevents ingestion of large amounts of the plant.

Peace lily (*Spathiphyllum* spp.)
The peace lily is cultivated in greenhouses for sale as potted plants and cut flowers. This plant is not a true lily. The white or green flowers are spathes rather than the tubular flowers of lilies. Leaves arise directly from the rhizome on long stems; they are dark green and from 1 to 5 feet long and $2^1/_2$ inches to 6 inches wide. Berries, borne in clusters on the remaining flower stalk, are not often seen. The entire plant contains calcium oxalate crystals. Biting into the plant or chewing plant parts causes irritation, burning, and stinging of the mouth, lips, and tongue. Vomiting and drooling may be seen. Intense pain in the mouth usually prevents ingestion of large amounts of the plant.

Philodendron (*Philodendron* spp.)
Philodendron spp. and *Monstera deliciosa* (split-leaf philodendron) are among the most popular house plants. They are cultivated in containers and large tubs for their attractive, deep green, glossy foliage. Leaves and stems contain toxic calcium oxalate crystals that can penetrate the mucus membranes of the tongue, lips, and mouth, causing intense burning and irritation. Signs of poisoning include burning and stinging of the lips, mouth, and tongue immediately after chewing on plant parts. Vomiting and drooling may be seen. In severe cases, swelling can make talking and breathing difficult. Intense pain in the mouth usually prevents ingestion of large amounts of the plant.

Pothos or devil's ivy *(Epipremnum aureum* or *Scindapsus aureus)*
Epipremnum aureum and *Scindapsus aureus* are very similar plants that differ only in the number of seed they produce. Both of these species, and their various cultivars, are called pothos, devil's ivy, and a number of other common names. Pothos plants are commonly grown as indoor vining potted plants and as ornamentals grown outside in warm climates. The leaves are heart shaped, shiny bright green, and splotched or marbled with yellow or white. In the tropics, the vines of mature plants can reach up to 40 feet long. The flowers are spathe shaped but are not seen on younger plants. The whole plant contains calcium oxalate crystals. Biting into the plant or chewing plant parts causes irritation, burning, and stinging of the mouth, lips, and tongue. Vomiting and drooling

may be seen. Intense pain in the mouth usually prevents ingestion of large amounts of the plant. Dermatitis has also been reported from plant exposure.

Shrubs and Vines That Contain Toxins

In general, shrubs cause very few of the cases of accidental poisoning reported to the California Poison Control System, but the category contains one very notable exception: oleander. More commonly, the Poison Control Center receives numerous calls about honeysuckle and berries from pyracantha, heavenly bamboo, holly, privet, and cotoneaster shrubs (see table 20.1). Fortunately, other than oleander, most of the others are not highly dangerous.

Angel's trumpet (*Brugmansia* spp.)

These plants are large semitropical shrubs or small trees whose common name, angel's trumpet, refers to the dramatic, large, pendulous, trumpet-shaped flowers that can be 5 to 10 inches long and 4 to 7 inches across at the open end. The flowers are shades of white, yellow, pink, orange, or red, depending on species and cultivar. Some have a delicate, attractive scent that is most noticeable in early evening. *Brugmansia* spp. plants are close relatives of jimsonweed (*Datura* spp.), and all parts of the plant possess toxic alkaloids of atropine, hyoscyamine, and scopolamine that can cause toxicity symptoms similar to jimsonweed poisoning. The leaves and seed contain the highest concentration of toxin. Symptoms include thirst, dry mouth, blurred vision, dilated pupils, increased heart rate, dry and red-hot skin, fever, inability to urinate, constipation, delirium, hallucinations, and death. Unpleasant symptoms can last for days.

Azalea and rhodendron (*Rhododendron* spp.)

There may be 1,000 species of rhododendrons. A generalized description includes plants that are evergreen, semievergreen, or deciduous shrubs that grow from 3 feet tall to small trees. The flowers come in various shades of pink but can also be white, yellow, orange, and lavender, and they are found in showy clusters. The entire plant contains grayanotoxin resins, but the toxin is concentrated in the foliage. Toxicity may occur from eating plant parts or contaminated honey and depends on the amount eaten. Symptoms include burning of the mouth, numbness and tingling of the mouth, drooling, nausea, vomiting, diarrhea, sweating, dizziness, decreased blood pressure, slowed heart rate, coma, fainting, altered mental status, and seizures. Deaths have been recorded in old literature, but no reports of death have occurred in modern medical literature. The signs and symptoms of poisoning generally last no more than 24 hours.

Cotoneaster (*Cotoneaster* spp.)

Members of the rose family, cotoneaster species vary from ground-hugging prostrate plants about 1½ feet tall to erect shrubs and small trees up to about 15 feet tall. There are semi-evergreen and deciduous species. The flowers are produced in late spring through early summer and can be single or in clusters of up to 100. They range from white to creamy white, light pink, dark pink, and almost red. The fruit is a small pink or bright red-to-orange berry that can be maroon or black when mature. It contains one to three (rarely up to five) seed. Fruit (berries) contain cyanogenic glycosides in low concentrations. There is very little information concerning the toxicity of this plant because the concentration is too low to cause a problem unless very large amounts are eaten.

English ivy and Algerian ivy *(Hedera helix, H. canariensis)*

English and Algerian ivies are well-known woody climbing evergreen vines that are cultivated throughout the warmer parts of the United States for ground cover or for climbing on walls, fences, and trellises. Leaves are generally lobed but squarish and lack lobes on flowering

branches of mature plants. The flowers are small, green, and inconspicuous, appearing in rounded clusters of 4 to 10. The fruit are black berries. All parts, especially the leaves and berries, contain hederagenin (a saponic glycoside) and several other saponins, which are potent skin sensitizers that cause dermatitis. The leaves are more toxic than the berries. Leaves may cause allergic contact dermatitis, with blisters and skin pigmentation. If poisonous parts are consumed in quantity, symptoms can include drooling, nausea, vomiting, abdominal pain, severe diarrhea, headache, fever, thirst, incoordination, weakness, difficult breathing, and coma.

Firethorn (*Pyracantha* spp.)
Another member of the rose family, the clusters of red-to-orange berries from the pyracantha shrub seem almost irresistible to young children. The plant is nontoxic, although the berries are bland and not very appealing in taste. The raw berries are considered edible and can be made into jams and jellies. If ingested in large quantities, nausea and diarrhea may occur. The long, sharp pyracantha thorns may cause dermatitis if they break the skin.

Flax *(Linum usitatissimum)*
Flax has long been cultivated for its linen fibers and seed oil (linseed oil). The flowers are pale blue or whitish and last only 1 day. The fruit are dry capsules, each containing 10 glossy, brown seed. Common flax can be found growing wild in areas of California. The whole plant, especially the immature seed, contains cyanogenic glycosides. Ingesting large quantities of seed, which have higher concentrations of nitrates and cyanide, can be fatal. Symptoms of poisoning include rapid breathing, progressing to shortness of breath and gasping, staggering, weakness, paralysis, convulsions, coma, and death. The toxin concentration varies among varieties of this plant, and those with low concentration are used as food sources. Cooked flax is considered edible.

Heavenly bamboo *(Nandina domestica)*
Nandina is an evergreen shrub up to 8 feet tall with narrow, 2-inch-long leaflets that turn red in the fall. The flowers are small and white. It has small red berries. There has been no record of toxic ingestion from this plant in humans. There is a single case of a dog that chewed on branches and stems and developed symptoms similar to cyanide poisoning. It is unknown why human poisonings have not occurred. It may be because humans eat only small amounts of plant parts or because the concentration in the berries may be very small. Ingestion of small numbers of berries is considered nontoxic.

Holly (*Ilex* spp.)
See the section “Flowers, Perennials, and Holiday Plants That Contain Toxins,” above.

Honeysuckle (*Lonicera* spp.)
Honeysuckle is a fragrant vining shrub that grows from 3 to 10 feet tall. The sweet-smelling flowers are creamy white to yellow and grow in pairs. Children may suck the sweet nectar out of the flowers, although that practice should be discouraged, as they may think that the nectar of all flowers is safe. The fruit is a red berry. Ingestion of berries from some European species has been reported to be fatal in Europe, but no toxic ingestions have been reported in the United States. American honeysuckle of the *Lonicera* genus is considered nontoxic.

Hydrangea (*Hydrangea* spp.)
See the section “Flowers, Perennials, and Holiday Plants That Contain Toxins,” above.

Lantana (*Lantana* spp.)
See the section “Flowers, Perennials, and Holiday Plants That Contain Toxins,” above.

Morningglory (*Ipomoea* spp.)
Morningglory is a common name for over 1,000 species of flowering vine plants. The flower usually opens in the morning and closes in the afternoon. Some morningglories, such as *Ipomoea muricata*, are night-blooming flowers. Flowers are tubular with flaring rim, to 4 inches long,

purplish blue to rose-lavender or white. The fruit is a papery-thin tan capsule, splitting to release small, black-pointed seed. There is some confusion as to which morningglory species are toxic. It is thought that all cultivars of *Ipomoea tricolor* are hallucinogenic and all species should be suspect. Seed may contain LSD-like substances. However, toxicity is unlikely due to the low concentrations, and a child who ingests a single flower is not going to develop symptoms of toxicity. There is a record of a 24-year-old male who chewed 300 heavenly blue seed and killed himself after experiencing hallucinogenic flashbacks. Several major suppliers of *Ipomoea* seeds now dust the seed with a noxious chemical fungicide to discourage consumption.

Oleander *(Nerium oleander)*

Oleander is a low-maintenance drought-tolerant evergreen shrub with showy, long-lasting clusters of blooms in white, pink, magenta, or dark red. Oleander can grow to 20 feet high, is cultivated as an outdoor ornamental, and is frequently grown in the median of California freeways. It has a bean-shaped fruit 4 to 7 inches long containing small seed. The entire plant, including dried leaves, contains the potent cardiac glycosides oleandrin, oleandroside, and neriin, which affect the heart if ingested. While the entire plant is very toxic, it is rare that a child would be poisoned from small, accidental taste exposures, partly because of the bitter taste of leaves. Poisoning from intentional large exposures would be expected to cause significant toxicity. Smoke from burning oleander affects sensitive people. Poisoning symptoms can include nausea, vomiting, abdominal pain, lethargy, and decreased heart rate. In more severe cases, symptoms include heart block, electrolyte imbalance, shock, and death. Skin contact with oleander leaves and branches may also cause dermatitis. Oleander wood should never be used as a cooking skewer. Although there are stories of people suffering fatalities from cooking food with oleander skewers and from using oleander branches or leaves in campfires, these reports are undocumented.

Pittosporum (*Pittosporum* spp.)

These evergreen trees and shrubs are widely planted in California. Controversy exists over the toxicity of this plant because it is also known as mock orange, but that common name is also used for *Philadelphus* spp. There is no evidence that pittosporum is toxic.

Privet (*Ligustrum* spp.)

Privet is an evergreen to deciduous shrub or small tree to about 30 feet tall with simple, dark green leaves 1 to $2^1/_2$ inches long. Some varieties may differ in leaf coloring, exhibiting white or yellow variegation. The flowers are small, white, and funnel shaped, appearing in clusters. Privets have drooping clusters of blue to black wax-coated berries that bear one to four seed. A case was reported in 1984 regarding a 5-year-old who suddenly developed severe abdominal pains, vomiting, and watery, yellowish diarrhea. He had no fever but did have a rapid pulse. The child was not hospitalized but died later that day at home. The father reported that the child had been seen eating berries of an unnamed ornamental hedge. The evidence implicating privet berries was circumstantial. In over 55 other reported cases involving ingestion of privets, only vomiting and diarrhea were seen. Most reports of fatalities due to privet ingestion are poorly substantiated and over 100 years old.

Wisteria (*Wisteria* spp.)

Wisteria is a woody vining shrub or small tree (up to 35 ft tall) that bears drooping clusters of fragrant flowers. The flower is similar in shape to the sweet pea and can be white to pink, blue, or purple. The plant usually blooms before it is in full leaf. The leaves have 13 to 19 oval leaflets that are about 3 inches long. Seed are contained in fuzzy 6-inch-long, pea-shaped pods. The pods and seed are the main toxic parts,

containing lectin and wisterin (glycosides), but all parts should be considered toxic. Symptoms include burning in the mouth, vomiting, stomach pain, and diarrhea that usually last about 1 to 2 days.

Yellow jessamine, Carolina jessamine *(Gelsemium sempervirens)*
Yellow jessamine is an evergreen found in home landscapes and also in freeway landscapes as a ground cover or climbing vine. The leaves are shiny dark green, and the plant has very fragrant, tubular, bright yellow flowers. It is one of the earliest plants to bloom each spring. The fruit is a small capsule with winged seed. The entire plant contains the alkaloid gelsemine. Even small amounts can be toxic to children. Children have been poisoned from sucking the nectar from the blossoms or chewing on leaves or flowers. The nectar can poison bees, and honey made from the nectar is toxic. Flowers, leaves, and roots can also cause dermatitis. Poisoning symptoms include dizziness, headache, dry mouth, difficulty swallowing or talking, seizures, shortness of breath, dilated pupils, double vision, muscle rigidity, decreased heart rate, and death from respiratory failure.

Trees That Contain Toxins

Trees are not the most common cause of accidental poisonings around the home, but a few species may present a hazard (see table 20.1). Handling the wood from alder, ash, beech, birch, cedar, elm, maple, mesquite, oak, pine, poplar, and spruce trees may result in dermatitis.

Apple *(Malus domestica)* and pear (*Pyrus* spp.)
Several hundred named varieties of apples and pears are grown in orchards and gardens throughout the United States. All varieties of apple and pear plant parts (excluding the fruit) contain cyanide, but the black seed inside the fruit core have the highest concentration. The seed must be well chewed to release the cyanogenic compound, amygdalin. While eating seed of the apple and pear is not recommended, eating an apple or pear, seed and all, will not result in any danger to a child or an adult. Accidental ingestion of whole seed is unlikely to result in cyanide toxicity, and cases of poisoning are very rare. Fatalities have occurred from intentionally eating (chewing) large quantities of apple or pear seed. Symptoms from eating large quantities of chewed seed include shortness of breath, weakness, light-headedness, seizures, stupor, heartbeat irregularities, cardiovascular collapse, coma, and death.

Black locust *(Robinia pseudoacacia)*
Black locust trees are large and coarse barked and can grow to 80 feet tall. They have stout, woody thorns along the trunk and branches. The leaves are compound, having 7 to 19 oval leaflets 1 inch long. The white to purple flowers are fragrant and grow in drooping clusters. The tree has a seedpod about 4 inches long. The flowers are nontoxic. The bark, leaves, and seed contain phasin, robin, and robitin (toxalbumins). The severity of symptoms depends on the amount of seed chewed. Toxalbumins cause severe irritation of the throat or stomach, similar to alkaline caustic burns. Symptoms include bloody vomiting and diarrhea and abdominal pain, with sloughing of the stomach and bowel tissues. Fever, drowsiness, lowered blood pressure, and shock can also be seen. Symptoms are usually seen in 2 to 6 hours after exposure. Two to five days after exposure, damage to the liver, central nervous system, kidney, and adrenal glands can occur. If the seed of these plants are swallowed whole, symptoms are much less likely to occur.

Buckeye and horsechestnut (*Aesculus* spp.)
Many species of *Aesculus* are planted as deciduous shade trees and ornamental shrubs that have white flowers. The native California buckeye *(A. californica)* is found in the Sierra foothills. The tree has one to six brown, shiny seed about 1 inch in diameter within a green, husked, valved

capsule. The seed has a conspicuous pale scar resulting in the term *buckeye*. All parts are toxic, although many of the reported cases of ingestion are of the seed. Aesculin is the glycoside found in the leaves and bark of various species. Older literature, not well documented, suggests that severe poisoning has resulted when children have repeatedly ingested significant quantities of the plant. In these old cases, symptoms include mouth irritation, fever, dilated pupils, vomiting, diarrhea, incoordination, muscle weakness, muscle twitching, paralysis, and central nervous system depression. Very few cases of human exposure have been reported in the literature. In modern times, horsechestnut or buckeye poisoning in humans resulting from single-seed ingestion usually causes only nausea, vomiting, and diarrhea. Significant poisoning from these plants is unlikely because the taste is too bitter to allow swallowing and the toxic substance is not well absorbed.

Chinaberry *(Melia azedarach)*

The chinaberry, a deciduous tree that can grow to be 20 to 30 feet tall, with a rounded umbrella-like shape, is adapted widely throughout California. The tree has clusters of fragrant, light to dark purple flowers in spring or early summer, followed by formation of hard, yellow, berry-like fruit that stay on the tree over winter. The ripe fruit is considered more toxic than the unripe fruit, but the bark, leaves, and flowers should also be considered toxic. The toxic principles are tetranortriterpene neurotoxins and an unknown gastroenteric toxin. Livestock and human poisoning cases have been reported in Africa and Australia. Northern hemisphere varieties do not seem to be as toxic. Signs of poisoning include nausea, vomiting, diarrhea, elation or depression, irregular breathing, incoordination, mental confusion, fainting, stupor, kidney damage, seizures, paralysis, and coma. Fatalities have been reported in other parts of the world.

Fig (*Ficus* spp.)

The *Ficus* genus holds a number of species with wide variation of size and other horticultural characteristics, including large trees grown as shade trees in warmer parts of California and small trees used as indoor plants. Edible figs are borne on deciduous trees grown in home orchards or for commercial production. Skin irritants that can cause dermatitis are present in the milky sap found in stems, leaves, and immature, unripe fruit. Sap is released when stems are cut, leaves are broken, or unripe fruit is picked. The irritants (no specific toxin) in the milky sap may cause itching, burning, redness, or blistering on contact. Symptoms can occur around the mouth if raw, unpeeled fruit is eaten or if young children chew on leaves of the plant.

Oak (*Quercus* spp.)

About 400 species of oak trees grow in North America, with numerous additional species found in Europe and the Middle East. Most are deciduous, but some retain their leaves during the winter and are known as live oaks. All produce an acorn (the seed) with species-specific characteristics of size and shape. The flowers appear in drooping clusters (catkins) in the spring. Oak pollen can cause allergies. Many species contain high concentrations of tannins and quercetin in their leaves, young sprouts, buds, and unleached or raw acorns. Native Americans made a flour out of acorns, but only after treatment to leach out the toxic principles. Children should be told not to chew on acorns. Fortunately, rather large quantities of raw acorns must be eaten before toxicity develops. In humans, signs of oak poisoning appear after several days or weeks. Symptoms include abdominal pain, constipation, thirst, frequent urination, bloody diarrhea, rapid but weak pulse, liver and kidney damage, and death.

Oak galls of more than 100 kinds are found in California. One form is that of an irregular ball, a lightweight, black and tan, corky sphere about the size of a golf ball.

Oak galls may attract the attention of young children or dogs when they fall from trees. Oak galls are a deformation of oak tissue resulting from insect activity, and they are not considered any more or less toxic than other parts of the oak tree.

Peach, plum, cherry, apricot, and nectarine *(Prunus spp.)*

These plants, like apples and pears, are in the rose family. Hundreds of varieties of peaches, plums, cherries, apricots, and nectarines are grown in home orchards and commercially throughout the United States. The familiar, fleshy edible fruit surrounds a hard, stony layer (endocarp) that contains a single seed. This seed, or kernel, is the most toxic part of the plant and must be well chewed to release the cyanogenic compound amygdalin. All parts of the trees (except the fruit) contain cyanide-producing compounds that are released when bark or leaves are eaten. The kernels have poisoned adults. Children have died from eating the kernels, chewing on twigs, or making tea from leaves. However, most of those cases were due to these plants being used as food in less-developed countries. Accidental ingestion of whole seed or pits is unlikely to result in acute cyanide toxicity, and cases of poisoning are rare. Symptoms from eating large quantities of chewed seed include shortness of breath, weakness, light-headedness, seizures, stupor, heartbeat irregularities, cardiovascular collapse, coma, and death.

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Diagnosing Plant Problems

21

Dennis R. Pittenger

Learning Objectives

Learn how to approach a plant problem.

Learn how to work with clientele and help gardeners experiencing plant problems.

Learn the causes of plant problems and their complexity.

Understand how to ask effective questions and gather information from clientele.

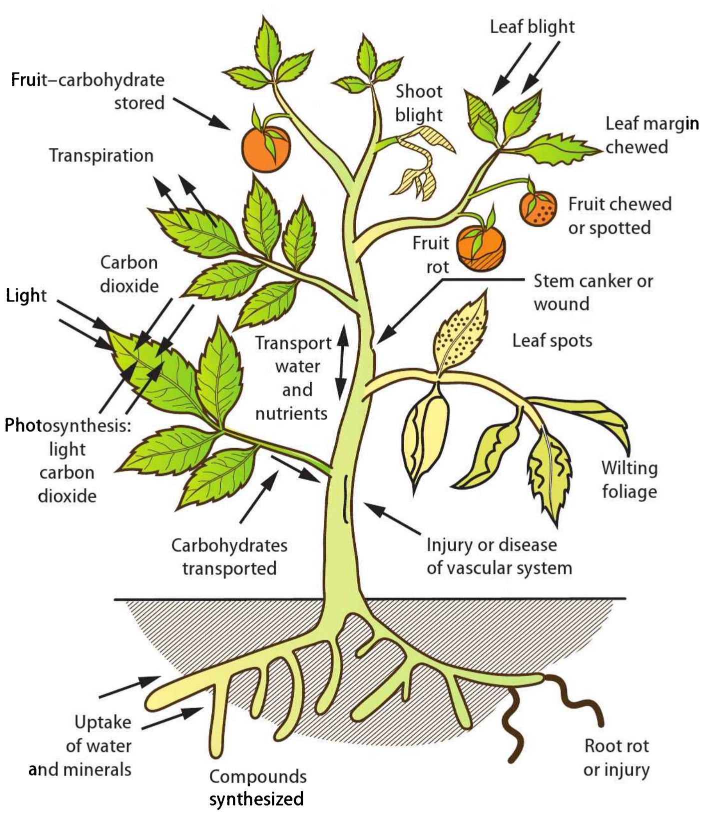
Learn how to formulate a diagnosis.

Diagnosing Plant Problems

Learning how to diagnose plant problems involves much more than memorizing a large number of photographs depicting symptoms of specific plant problems. Symptoms can be a guide to the cause of a given problem, but be aware that a disease or disorder may not produce the same symptoms in each occurrence, and many plant problems produce a variety of symptoms that are not always consistent in appearance. Also, a plant problem can be the result of more than one factor. It is difficult to teach and learn diagnostics; experience is necessary to become skilled. Successful diagnosticians are good detectives who develop a systematic approach to problem solving, ask many questions, keep an open mind, draw on their knowledge of plant growth and development, and consult available facts or references before they offer a diagnosis. In many instances, it is possible only to narrow the causes of a plant problem to two or three possibilities or to offer a tentative diagnosis.

Figure 21.1

Pathogens, insects, other pests, or environmental factors can disrupt plant processes or injure plant tissues. When they do, a plant often responds by producing symptoms. *Source:* After Hasey 1985, p. 4.



A primary function of a master gardener is to help people through education. Thus, master gardeners should use the process of diagnosing clients' plant problems as a "teachable moment" and an opportunity to teach basic concepts of plant growth, development, and sustainable culture as well as help to solve a problem. Understanding what went wrong helps prevent the problem from recurring and save remaining plants.

Knowledge Needed to Diagnose Plant Problems

Diagnosing plant problems requires a basic level of knowledge in horticultural science, entomology, plant pathology, and soil and irrigation management. These topics are addressed in detail in specific chapters in this book. Although a few general concepts are provided here, a thorough review of those chapters is recommended before actively diagnosing plant problems.

Basic Horticultural Science Concepts

The primary plant processes (photosynthesis, respiration, transpiration, translocation) are affected greatly by the environmental factors of light, temperature, water availability, and soil conditions. Suboptimal environmental conditions, as well as pest activities, improper cultural practices, or human activity, can disrupt or limit these primary plant processes or injure plant tissues, resulting in a sick or abnormal plant that expresses symptoms (fig. 21.1). Frequent or persistent suboptimal growing conditions cause plants to develop symptoms subtly over a period of time. Healthy plants are typically less susceptible to serious insect, disease, or abiotic problems.

Every plant has certain genetic capabilities and limitations that dictate what the normal plant should look like, what its expected life span will be, and what its mature size will be under a given set of environmental and growing conditions. You must know what normal is to determine whether a plant's condition or appearance is abnormal. When a plant's size, color, flowering, growth rate, or other features are noticeably abnormal, investigate possible causes. You must also understand how environmental conditions may affect a given plant's vegetative and flowering (reproductive) growth phases.

Knowledge of the basic cultural practices needed by plant species is essential to diagnosing problems. Planting and establishment procedures, fertilizer needs, irrigation needs, and other requirements must be known.

In diagnosis, identification of the affected plant is the first step. Thus, good plant identification skills and knowledge of plant identification references can facilitate faster, more accurate problem diagnosis and instill confidence in the client. Most references on plant pests and problems are organized by plant species, so knowing or being able to find the plant's scientific name is usually essential for using them.

Plant Insect, Mite, and Disease Concepts

When a plant dies, looks somewhat abnormal, or is growing poorly, many untrained gardeners automatically assume that an insect or disease is the cause. This is especially true if there are active insects on or near the plant or if foliage is distorted in some fashion. The mere presence of an insect does not correlate with its being a pest, however. Not all insects found on a sick plant are the cause. Some may be beneficial insects, or they may simply be there by chance. In many instances, improper cultural practices or some other nonpest issue is the cause of the problem. Factors that may predispose a plant to pest infestations (e.g., drought, overirrigation, overfertilizing, improper planting techniques) must always be considered. Basic knowledge about insects, mites, and diseases will enable a diagnostician to more accurately and rapidly reach an accurate diagnosis of the problem or determine whether the plant is actually growing normally.

It may be difficult to become familiar with all of the different insects and mites that damage plants, but it is possible to learn to recognize the various types of damage caused by different types of insects and mites. If you recognize the type of damage and you know the identity of the host plant, you can sometimes diagnose the pest involved using reference books, including this handbook and other University of California publications. Additional information on diagnosing plant problems caused by insects and mites is found in chapter 7, "Insects."

Signs versus symptoms. A good diagnostician must gain a working knowledge of the symptoms and signs of common plant diseases. A disease symptom is a change in the appearance or growth of the plant, such as wilting, galls, leaf spots, blights, and root rots. A disease sign is a disease-causing organism or its parts, such as the white, powderlike mildew (visible fungal structures) seen on a plant

affected by the disease powdery mildew. If you can recognize the symptoms or signs and identify the host plant, you can use various reference materials to make, or at least narrow down, a diagnosis. When examining a plant sample, note all symptoms and signs. Recall that the expression of symptoms does not mean that a plant has an infectious disease.

Other Animal Pests

Sometimes animals other than insects and mites affect plants. Deer eat the bark from trees, pull up tulips, and prune shrubs; mice feed on plant roots or tree crowns, causing wilt; gophers, ground squirrels, and moles sever the roots or girdle stems; birds peck holes in trees or eat vegetable seedlings; dogs and cats mark their territory by spraying objects, turf, and landscape plants, causing blighted shrubs, grass, and flowers.

Diagnosing Plant Problems

A diagnosis is the process of gathering information about a plant problem and determining the cause. Solutions or recommended treatment options can be suggested once the diagnosis has been completed. Diagnosing problems usually involves a great deal of detective work and investigation to obtain adequate information and clues. Determining the basic causes of poor plant performance is difficult because a diagnostician must often analyze incomplete evidence. The diagnostic process entails gathering historical and management information from the person caring for the affected plant and sometimes noting visual signs, symptoms, and other evidence from a specimen submitted, organizing the information, then drawing on past experience, references on the subject, and other resources to reach a conclusion. Unfortunately, it is often not possible to visit the site where the specimen was taken. In most cases, a visit to the site yields additional information that could facilitate diagnosis. However, alternatives such as digital photographs and Internet links can give you a look at the site.

Basic Causes

Poor plant performance is attributable to a wide variety of causes, some of which act alone and others of which act collectively. Plant problems can be classified as abiotic or biotic. A partial list includes the following.

Abiotic causes: Improper cultural practices or conditions, including

- water excess or deficiency
- poor drainage
- deficient or excess light
- physical or chemical injury
- poor adaptation to growing site
- temperature too high or low
- excess or deficient fertilizer nutrients

Biotic causes:

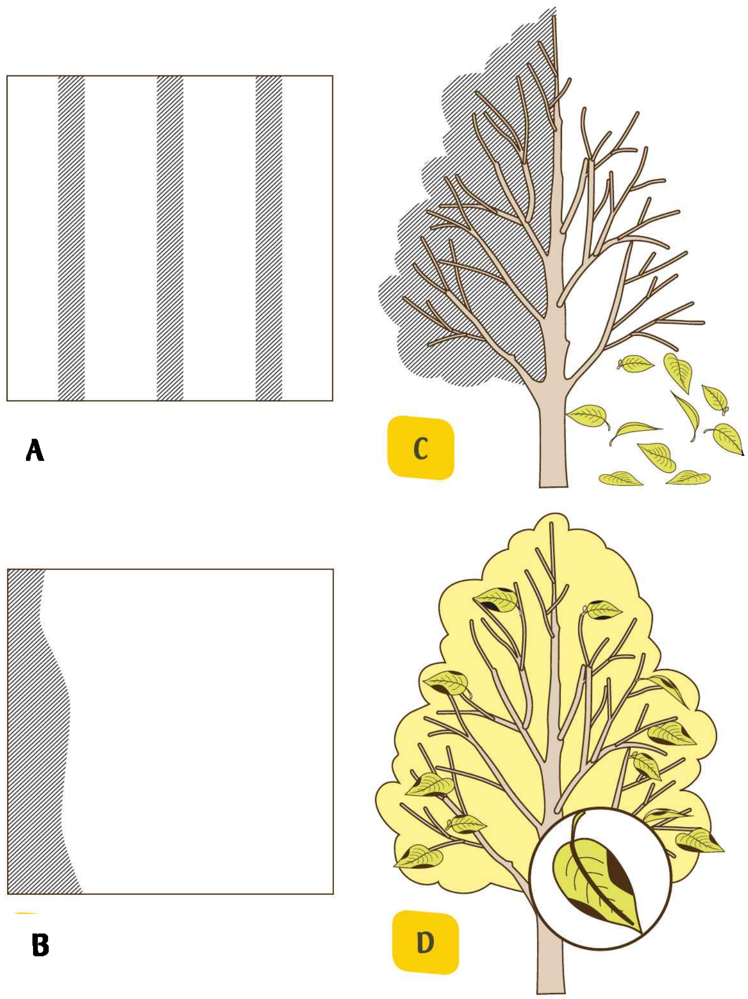
- insects and their relatives
- plant disease

The majority of plant problems found in California home gardens are caused by improper plant selection or poor cultural practices, as opposed to diseases, insects, or the chemical or physical properties of the soil. Improper planting, irrigating, and fertilizing are the most commonly misapplied cultural practices. Mishandling or misapplying herbicides is also a common problem.

Remember that real problems are always caused by something. A logical explanation or solution can usually be found, and if you are serving a client, your job is to try to identify it. However, always be conservative when the evidence or information available is incomplete or inconclusive and admit that you are not sure of the cause or can only narrow the cause to a few possibilities. Inform the client that you will seek the advice of more experienced diagnosticians if you cannot narrow the cause sufficiently. If local Master Gardener Program policies permit, it is acceptable to make an educated guess as

Figure 21.2

Patterns of plant symptoms. Symptoms in turfgrass areas may produce regular patterns (A) or irregular patterns (B). In woody plants, determine whether whole areas of the plant (C) or selected portions or a few leaves (D) are showing symptom patterns.



long as the client understands that is what is being offered.

Steps in Diagnosing Plant Problems

There are five general steps in diagnosing plant problems. Each master gardener should develop a method of questioning and information gathering based on the steps outlined below. An effective diagnosis requires considerable experience. Always be courteous to clients, focus on helping them identify practical solutions to their problems, and educate them to prevent the problem from recurring. Be prepared to say, "I don't know, but I will investigate further." Table 21.1 is a sample checklist for plant diagnosis that may be helpful.

Step 1. Identify the plant
Determine the common and scientific name of the plant. Failure to do this can make an accurate diagnosis difficult. Use the resources in the bibliography at the end of this chapter. Many UC publications and websites use scientific names to correlate plants with their common pests or problems, so you usually need to know a plant's scientific name to effectively use these references.

Step 2. Define the problem
Examine the plant carefully, including the roots if possible (especially for container plants). What is abnormal about the plant? Note symptoms or signs of pests and determine what, if anything, is abnormal about the plant. Are many or few plants affected? Which plant parts are affected? Are symptoms on one or several species? Keep an open mind and avoid snap conclusions as to the problem's cause.

Step 3. Collect information
Ask questions and make observations about the soil and site conditions, the cultural practices that were followed, applications of any pesticides (including which ones, frequency, and dosage), approximate age of the plant, past and present weather conditions, and other relevant information. You may have to proceed with incomplete information regarding cultural practices. Eliminate any obvious or very common causes first. Look beyond the immediate symptoms for clues.

Step 4. Look for patterns
If more than one plant or a large area is affected, look for patterns in the distribution of the problem or symptoms among plants in the area (fig. 21.2). Check for patterns on individual plants by observing the range of plant tissues affected and the severity of the problem on and among plant parts. Compare old and new growth; leaf margins, tips, and whole leaves; and so on. Observe whether there are patterns

Table 21.1.

CHECKLIST FOR PLANT DIAGNOSIS

Plant information

A. Species and cultivar ______________________

B. Source of plant ______________________

C. Plant age or date planted ______________________

D. Location of affected plant
  1. Shade or sun ______________________
  2. Outdoor or indoor ______________________
  3. Exposure (N, S, E, or W) ______________________
  4. Near building ______________________
  5. Container, or planted in the ground ______
  6. Wind exposure______________________
  7. Proximity to utilities (lines, trenches, leaks) ______________________
  8. Root disturbance (excavations) __________
  9. Proximity to hardscape, bodies of water, other landscaped areas (i.e., near or in turf area, next to driveway) ______________

Problem description

A. Description of symptoms
  1. Plant parts affected ______________________
  2. Chlorosis ______________________
  3. Wilts ______________________
  4. Leaf spots ______________________
  5. Leaf distortion ______________________
  6. Rots (soft, firm, stem, or root) __________
  7. Other (specify) ______________________

B. Degree of symptom expression
  1. Whole plant ______________________
  2. In isolated section of plant ______________
  3. A few leaves or shoots ______________
  4. A few roots ______________________

C. Are symptoms on the entire planting or isolated on a few plants? ______________________

D. How many plants with symptoms
  1. 1–2 plants ______________________
  2. 10% ______________________
  3. 25% ______________________
  4. 50% ______________________
  5. 75% ______________________
  6. 100% ______________________

E. Length of time symptoms observed (days, weeks, months) ______________________

Soil information

A. Texture
  1. Light (sandy) ______________________
  2. Medium (loam) ______________________
  3. Heavy (clay) ______________________
  4. Other (specify) ______________________

B. Drainage ______________________

C. Grade changes or other disturbances ______________________

D. Has soil been amended? ______________________

E. Compaction evident? ______________________

F. Water infiltration and percolation ______________________

Fertilization

A. Rates ______________________

B. Application method ______________________

C. Frequency or timing of applications ______________________

Pesticides or other materials used

A. Type (insecticide, herbicide, fungicide, other) ______________________

B. Product name ______________________

C. Rate, concentration ______________________

D. Application date and frequency ______________________

Watering

A. Method(s) ______________________

B. Frequency ______________________

Recent weather conditions

A. Day and night temperature patterns ______________________

B. High winds ______________________

C. Rain or hail ______________________

Plant or soil testing

A. Prior diagnosis provided?
  1. Who provided it______________________
  2. Results ______________________

B. Sample collection procedure ______________________

of wilting in young shoots versus older ones or across the entire plant. Look for patterns of chlorosis, yellowing, and malformed leaves. Note if there is any abnormal defoliation or dieback in portions of the plant. Check to see whether plants of the same species are affected or symptoms or signs are present on multiple species. Try to compare a normal plant (or part of a plant) with one that shows mild symptoms and one that shows severe symptoms.

Attempt to observe the root system, if possible. Look to see if the fine roots are healthy; these will be white or light colored when healthy, or they could be light colored inside with a dark covering. They will be discolored, black, or rotted when unhealthy. A common misconception is that being able to pull off outer root tissue with your fingers (leaving the stringlike center of the root behind) is a good sign that root rot is present. This is not a reliable symptom of root rot, however, as the healthy roots of some plants may be scraped or damaged easily.

There may be more than one problem, and one can cause another. Also, consider past weather conditions and compare them with the affected plant's environmental requirements and those of its common insect, mite, or disease pests.

Step 5. Formulate a tentative diagnosis
A tentative diagnosis often means that the cause of the problem can be narrowed to two or three possible answers. Base the diagnosis on the evidence and information collected, along with your knowledge of the plant and its needs and common problems. Attempt to confirm a tentative diagnosis or narrow the possible causes by focusing on further examination of the plant, collecting more detailed information, consulting references or colleagues, and, if feasible, using laboratory services for soil and pest analysis. Keep in mind that the problem may be new or unique, and you may not be able to make a diagnosis. If a pest problem appears to be something new, work with your UC Cooperative Extension advisor to determine whether contacting the local county agricultural commissioner would be appropriate to determine if the pest is new or invasive to the area.

Communicating with Clients over the Telephone and by E-mail

In order to help and teach clients, a diagnostician must develop effective communication skills in asking questions. These skills are particularly important when diagnosing plant problems over the telephone or in any situation when the affected plant and its setting are not accessible. Take control of the conversation by following a logical line of questions that provides the information needed to solve the problem. Allowing the client to do most of the talking is best. Asking effective questions takes some experience and a great deal of thought, especially when attempting to diagnose a problem in a telephone conversation. Questions must be phrased in such a way that you get a clear picture of the plant's symptoms, size, and age, along with the cultural practices followed. Comparing this information to general knowledge and understanding of how the species in question should grow and develop makes it possible to assess what is abnormal and how the problem might be solved. To form an accurate diagnosis is important; you may need to request a sample that shows symptoms and healthy parts of the affected plant (see the section "Sample Collection and Laboratory Testing," below).

Once the ailing plant has been identified, getting answers to the following questions will help you complete the five steps in diagnosing plant problems that were presented in the previous section.

How old is the plant, or when was it planted?

- What size is the plant (how tall, wide, etc.)?
- What size are the leaves? Describe them to me.
- Where is the plant located (describe its setting)?
- What fertilizers, soil amendments, pesticides, or other materials have been used on the soil and plant?
- How often and how much do you irrigate the plant and how is the water applied?
- Does the soil drain well after receiving irrigation or rainfall? Is it wet most of the time?
- How would you describe the symptoms?
- When were the symptoms or problem first noticed?
- What part of the plant appears to be affected or abnormal?
- How many plants are affected? Do different types of plant seem to be affected?

Answers to these questions usually provide insight into what are potential causes of the problem. Additional questions can be asked to narrow the possible cause or causes of the problem. Frequently, plants suffer from multiple difficulties.

Equipment and Tools Helpful in Diagnosis

Many items can be useful, even essential, in making a diagnosis of a plant sample or the site where a problem plant is growing. Some of the most commonly used tools include

- sharp knife
- hand lens
- soil probe (an Oakfield tube or similar tool)
- shovel
- pick or mattock
- pruning shears
- plastic bags and ties (for collecting plant, pest, or soil samples)
- small vials with lids (for insect samples)
- permanent marker and labels
- notebook and pencil
- portable plant press (for making reference specimens)
- digital camera (to record site and observations and send images to colleagues)
- binoculars (for viewing upper portions of tall trees)
- insulated cooler (to keep samples cool and fresh in warm weather)

Because horticultural science and plant problem solving include a large knowledge base, good diagnosticians also know where to search for more information regarding plants, their specific needs, and their potential problems. It is essential for a diagnostician to become familiar with reference books, keys, various UC websites, and other materials (see the bibliography at the end of this chapter) that can be consulted and used in conjunction with personal experience in plant problem solving.

Working with Clients and Assisting Gardeners

When you are diagnosing clients' plant problems, they view you as the expert and usually expect a quick, succinct identification of the problem and a simple cure for it. Occasionally, clients are only trying to get you to agree with or to confirm their own suspicions or inaccurate diagnoses. Also recognize that sometimes clients are embarrassed that they may have done something to cause the problem and they may not tell the whole truth about the practices they have followed. Always maintain a good “plantside manner.” Be courteous, personable, and sincere in helping clients identify practical solutions to their problems.

Focus on teaching clients so that they can grow plants with minimal future problems. Use your knowledge and remain

confident in your abilities to find answers. Explain to the person you are assisting that diagnosis is often difficult because many problems are the result of complex interactions of plants, pests, and the environment. Respectfully disagree with a client's perceptions or conclusions about the problem if appropriate, but be certain to explain to the client why he or she is wrong, based on your knowledge of horticultural science and related disciplines covered in this book and the reference materials you consulted.

Involving clients in diagnosing a problem and identifying solutions provides an excellent opportunity to educate them about their plants' cultural requirements and common pest problems. Sharing your expertise during this process may give clients enough knowledge to allow them to solve their own problems in the future. In these circumstances, your role is that of an educator and facilitator, not a doer.

In today's high-technology world where communications occur rapidly and diagnosis of human health problems is often executed quickly and precisely, gardeners typically expect diagnosis of plant health problems to be completed just as rapidly and precisely. However, diagnosing plant problems can be more difficult and less precise than diagnosing human ailments because the affected plant(s) cannot communicate directly with the diagnostician. In addition, the plant diagnostician deals with thousands of host species, each with a number of unique potential pests, problems, and symptoms, whereas the medical professional knows one species and its pests, problems, and symptoms. Cost factors can also limit the appropriateness of laboratory testing for garden-related plant problems. Finally, the technology for solving plant problems is often much more limited. If a gardener is disappointed with the speed or precision of a plant problem diagnosis, it may be necessary to relate these concepts to him or her so that the frame of reference and expectations are based on realistic perceptions of the factors involved in diagnosis.

Recognize that not all plant problems can be treated: a treatment may not exist, is not practical, or is not cost effective. Clients often do not like to hear this, so you must educate them fully about the problem and how to avoid it in the future.

Providing Solutions and Options

Once you have correctly diagnosed the problem, effective solutions are available from a variety of reference materials from the University of California, such as the UC IPM website and many other UC publications and web-based resources, and other reliable and unbiased sources. See the bibliography of this chapter for a list of highly useful resources. The diagnosis may consist of two or more likely but unconfirmed causes. If so, offer potential solutions or treatment options for each possible cause. Not every plant problem can be solved or cured. Sometimes it is simply best to remove and replace affected plants. This may be particularly true when clients fail to recognize or become concerned with a troubled plant until it is too severely damaged to be treated effectively.

Give the client the entire range of treatment or solution options, as articulated in published or web-based UC guidelines or recommendations, then allow the client to decide which option is best for them to employ. In the case of a specific insect or disease pest, for example, discuss and provide information about cultural practices, pesticides, and other possible alternatives that could manage the pest and reduce its damage. Give the strengths and weaknesses of each option, if known, along with indicators of improvement or success expected to result from choosing a particular option. When plant symptoms appear to be the result of improper pH, salinity, or nutrient levels, it is often inexpensive, effective, and practical for the home horticulturist to apply a treatment for the

suspected problem, then observe whether the plant improves. Also explain the likely consequences of doing nothing about the problem. Clients must decide on their own which solution(s) best match their interests.

Certified UC master gardeners must follow specific statewide and local policies on providing management and pesticide options. Policies are available online or at UC Cooperative Extension offices. All options presented for a client to consider must be based on published or web-based UC guidelines or recommendations, such as those found in the UC IPM website's Pest Notes, Pest Management Guidelines, Quick Tips, and other guides specifically for UC master gardeners (see ipm.ucdavis.edu). Other UC sources for management options include the UC Garden Web and various home garden–related publications.

Sample Collection and Laboratory Testing

In certain cases, a sample of the affected plant or suspected pest is very helpful in reaching or confirming a diagnosis. Samples can be especially useful if the affected plants cannot be viewed in person or if further, detailed study of the plant tissue is needed. Before taking a sample or requesting a client to provide one, consider how the sample might help in reaching a diagnosis. If the need is questionable, obtaining a sample may not be warranted.

Samples of soil surrounding the affected plant can also be useful in reaching or confirming a diagnosis. Soil can be analyzed for important chemical properties (pH, salinity, and levels of essential plant nutrients or toxic elements) and physical properties (texture and bulk density) if one or more of these components is seriously suspected as the cause. Testing soil for disease organisms, however, is usually not practical for diagnosing home garden problems because the laboratory tests are relatively expensive. Similarly, it is generally not feasible to test soil for the presence of nonspecific plant-toxic chemical substances. Soil analysis can reveal the level of nutrients contained in the soil. Both soil analysis and plant tissue analysis for nutrient content are needed to determine whether the plant is taking up enough nutrients.

Following proper techniques and procedures when collecting plant, soil, or other samples maximizes their usefulness in reaching or confirming a diagnosis. Place samples of plants and soil in plastic bags and refrigerate them to maintain freshness.

Plant samples should include as much of the affected plant as is practical. Attempt to get a whole branch or several small stems of a tree rather than just one or two leaves, for example. Larger portions of plant tissue often allow the evaluation of general plant health. Always seek to get samples of both healthy and unhealthy plants or plant parts so that they can be compared. Try to include plant samples that have a transition between healthy and unhealthy plant tissues. Samples of the root system are often helpful when soil-related causes are suspected. For turfgrass problems, a minimum of 1 square foot of turf is usually necessary; the most useful sample includes turfgrass that is healthy, unhealthy, and of intermediate condition.

Typically, about 1 pint of soil is needed to conduct soil tests. The sample submitted should be a subsample from a mixture of small samples taken at various depths and locations from the area where affected plants are growing.

Insect samples should be placed (dead or alive) into small vials, boxes, or other containers that will protect them and keep them intact. Baby food jars or similarly-sized containers are useful for this purpose.

The University of California does not operate plant, soil, or pest diagnostic laboratories for the public. Clients can obtain plant and soil analysis from commercial laboratories around the state (see "Laboratories, Analytical" in an online search or telephone directory). In some counties, the

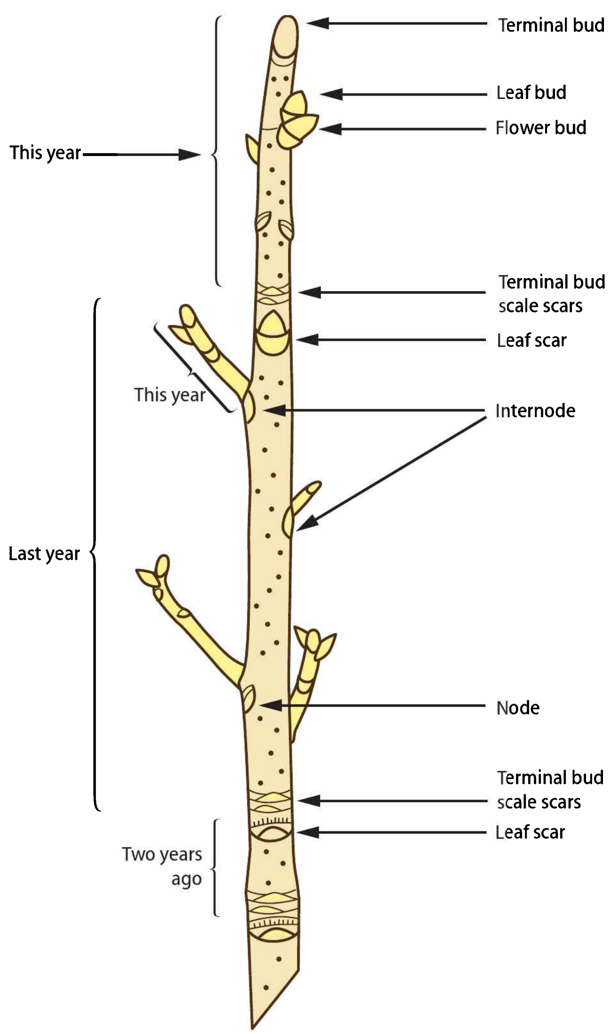
county agricultural commissioner's office will provide insect and plant disease identification services. Before submitting any type of samples to a laboratory, contact them for information on prices and sample requirements. Master gardeners do not submit samples for laboratory analysis on behalf of home gardening clients, but they can provide advice on sampling and shipping procedures.

Diagnosing Problems in Various Types of Plants

California gardeners grow a wide variety of plant materials, including tropical, subtropical, and temperate landscape plants; vegetable and fruit crops; and indoor plants. The following tips address problem solving in general and for particular groups of plant materials. In addition, the other chapters in this book that address specific crops include useful information on pests and problems associated with the respective crops.

Figure 21.3

Growth structures of a woody plant stem.



General Tips

Whenever an entire plant shows wilting or general decline and poor vigor, first evaluate the root system and main stem or trunk for evidence of injury or other disorder. If individual branches or shoots express these symptoms, examine the base of the branch or shoot or look for an area of transition from healthy to unhealthy plant tissue. This may involve cutting just under the stem surface at the point of transition to see if there is insect damage or disease symptoms or signs present.

Wilting, leaf scorch (brown margins), and general yellowing of all foliage are often symptoms of soil problems or of a disorder in the vascular system or root system. Evaluate soil moisture content, irrigation management, fertilizer practices, and root and stem tissues first to eliminate them as causes before looking further.

Woody Plants

When diagnosing problems in woody plants, determine the size of the plant, its vigor, and the general site conditions surrounding the plant. Remember that there is sometimes a delay between when a problem occurs and the appearance of symptoms or recognition by the client that something is wrong with the plant. To determine whether twigs or small branches are alive, lightly scrape the thin bark covering with a thumbnail. If it peels easily and the tissue immediately underneath is greenish or whitish, the stem is alive; if it is hard to scrape away or the tissue underneath is not greenish or whitish, it is likely dead. Plant vigor, both past and present, can usually be evaluated by mea-

suring the distance between the terminal bud scale scars. Each growing season, many woody plants, especially deciduous and broadleaf evergreens, form terminal buds at the ends of shoots and branches (fig. 21.3). When new shoot growth emerges from these buds, a scar (small noticeable ridges or rings) remains on the stem where the bud scales were. The distance between any two bud scale scars or the existing shoot tip and last year's bud scale scar can be measured to judge the amount of growth the plant has made. A tree that is dying or is "suddenly" dead will often show small amounts of growth over the past few years, which means the plant has been in decline for some time.

Site and cultural history are useful in narrowing the causes of the decline to such common factors as poor irrigation management, root system injury or disruption, compacted soil, grade changes, poor planting technique, or a combination of these factors. Declining plants are also vulnerable to attacks by insect and disease pests that do not usually infest vigorous plants. In some cases, insect and disease problems that would not damage a healthy plant will kill a declining one.

When woody plants decline or die, assess the root system's health. Suspect a root injury or disorder when an entire plant declines or dies. Digging out or around newly planted woody plants makes it possible to evaluate their root systems. For older established plants, root health can be evaluated by digging small holes or slices, or by inserting a soil probe in several locations at various distances from the base of the plant. It is usually necessary to explore about 1 to 2 feet deep, since most of the root system will be present in this zone. Look for numerous fine roots ($^1/_{10}$ in in diameter) that are firm and entirely white or white inside with a dark outer cover. If very few fine roots are found or if they are soft, rotten, and brown, the root system may not be vigorous and healthy enough to support the plant.

Herbaceous Plants and Vegetables

Plants in this group are typically planted in masses, and their root systems are more accessible. Look closely for patterns of symptoms and incidence of the problem among plants wherever possible. Carefully check their root systems and bases of their stems or crowns for signs of soil-related problems or damage to these tissues from pests or other injuries. It may be feasible to remove entire plants for evaluation without destroying the whole planting. These plants are often easy to replant and re-establish if a serious, difficult-to-treat problem is present or if the diagnosis cannot pinpoint the exact cause of the problem.

Indoor Plants

Indoor plants largely depend on the grower for their needs, and obtaining detailed information from clients about the care given to the plants will usually guide you to a diagnosis. Always evaluate the root system of these plants by removing them from the container (where possible). Assess light levels provided and determine whether any sudden changes have occurred in light levels. Weak, spindly growth is a key symptom that light is inadequate.

Proper soil moisture and aeration levels are critical to maintain healthy container-grown plants. Attempt to determine whether proper watering and fertility practices are being followed. General decline, yellow foliage, scorched leaves, and stunted growth are symptoms that these factors are not optimal. Closely observe foliage and stems for mites, scales, aphids, mealybugs, and whiteflies. These are common pests of indoor plants that can quickly cause plants to decline.

Lawns

Many lawn problems are described as "brown patches in the turf," which can be caused by any number of things. Lawn pests often occur in only certain seasons or during certain weather conditions and

only on certain species of turfgrass. Knowledge of these components aids in narrowing the potential causes. Improper irrigation (too much, too little, too frequent) often contributes to pest problems and is sometimes the sole cause of brown turf. Look for patterns of symptoms, carefully evaluate the root system, and assess the thatch development when turf problems occur. Damage to turfgrass can often be repaired easily, but it is beneficial to teach the client proper turf management practices so that future problems are minimized.

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Useful Conversions

Measurement Conversion Table

To use this conversion table, find the unit of measure for the value you know in column A or B. If the value you know is in column A, multiply it by the factor in column A to B to get the converted value in the units of column B. If the value you know is in column B, multiply it by the number in column B to A to get the converted value.

For example, how do you convert 10 miles to kilometers? In the table below, miles are in column A; kilometers are in column B. The conversion factor for A to B is 1.61; 10 miles × 1.61 = 16.1 kilometers.

A to B	COLUMN A	COLUMN B	B to A
	Length		
0.083	inch (in)	foot (ft)	12
2.54	inch	centimeter (cm)	0.394
0.333	foot	yard (yd)	3
0.000189	foot	mile (mi)	5,280
0.305	foot	meter (m)	3.28
0.000568	yard	mile	1,760
0.914	yard	meter	1.094
1.61	mile	kilometer (km)	0.62
	Area		
6.45	square inch	square centimeter	0.15
0.093	square foot	square meter	10.764
43,560	acre (ac)	square foot	0.00002
43.56	acre	1,000 square feet	0.02296
0.405	acre	hectare (ha)	2.47
640	square mile	acre	0.00156
2.59	square mile	square kilometer	0.386
	Volume		
0.333	teaspoon (tsp)	tablespoon (tbsp)	3
4.9	teaspoon	milliliter (ml)	0.2
14.79	tablespoon	milliliter	0.07
2	fluid ounce (fl oz)	tablespoon	0.5
0.125	fluid ounce	cup (liquid)	8
0.0625	fluid ounce	pint (liquid)	16

Measurement Conversion Table, cont.

A to B	COLUMN A	COLUMN B	B to A
	Volume		
29.57	fluid ounce	milliliter	0.034
0.5	cup, liquid (c)	pint, liquid (pt)	2
0.5	pint, liquid (qt)	quart, liquid	2
28.875	pint (liquid)	cubic inch	0.0346
0.473	pint, liquid	liter (l)	2.11
0.55	pint, dry (pt)	liter	1.82
57.75	quart, liquid (qt)	cubic inch	0.0173
0.946	quart. liquid	liter	1.056
1.1	quart, dry (qt)	liter	0.91
4	gallon (gal)	quart, liquid	0.25
231	gallon	cubic inch	0.00433
0.1337	gallon	cubic foot	7.48
3.79	gallon	liter	0.265
4.173	gallon per ton	liter per metric ton	0.239
0.0038	gallon	cubic meter	264
0.035	bushel (bu)	cubic meter	28.37
0.000579	cubic inch	cubic foot	1,728
27.0	cubic yard	cubic foot	0.037
28.317	cubic foot	liter	0.353
0.765	cubic yard	cubic meter	1.307
1,000	liter	milliliter	0.001
1.0	milliliter	cubic centimeter	1.0
	Mass (Dry Weight)		
0.0625	ounce (oz)	pound (lb)	16
28.35	ounce	gram (g)	0.035
0.0005	pound	ton	2,000
454	pound	gram	0.002
0.454	pound	kilogram (kg)	2.205
0.001	gram	kilogram	1,000
0.907	ton (T)	metric ton (t)	1.102
	Mass or Volume per Area		
0.02296	pound per acre	pound per 1,000 sq ft	43.56
1.12	pounds per acre (lb/ac)	kilogram per hectare (kg/ha)	0.89
2.24	ton per acre (T/a)	metric ton per hectare (t/ha)	0.446
0.02296	gallon percre	gallon per 1,000 sq ft	43.56
2.938	gallon peracre	ounce per 1,000 sq ft	0.3403
9.36	gallons per acre	liter per hectare (l/ha)	0.106
0.893	kilogram per hectare	pound per acre	1.12
0.0205	kilogram per hectare	pound per 1,000 sq ft	48.79
0.107	liter per hectare	gallon per acre	9.35
	Temperature		
(°F – 32) × 0.5555	Fahrenheit (°F)	Celsius (°C)	(°C × 1.8) + 32

Measurement Conversion Table, cont.

A to B	COLUMN A	COLUMN B	B to A
Concentrations			
0.0001	ppm	percent	10,000
0.013	ppm	oz by weight in 100 gallons	76.9
0.781	oz by weight per gallon	percent	1.28
0.125	lb per 100 gallons	percent	8
0.1	gram per liter	percent	10
0.1	gram per kilogram	percent	10
1,000	gram per liter	parts per million	0.001
Water and Irrigation Measures			
7.48	cubic foot	gallons	0.134
0.00133	gallon	100 cubic feet, of water (hcf)	748
748	standard billing unit (BU)	gallon	0.00133
1.0	milliliter (water)	gram	1.0
62.4	cubic foot	pounds of water	0.016
8.34	gallon	pounds of water	0.120
0.000023	cubic foot	acre-foot	43,560
0.0000031	gallon	acre-foot (ac-ft)	325,829
0.0000368	gallon	acre-inch (ac-in)	27,152
102.8	acre-inch	cubic meter	0.0097
1,233	acre-foot	cubic meter	0.000811
0.623	in. water	gallon per square foot	1.61
inches of water applied × sq. ft. of irrigated area × 0.623	inches of water applied	gallons of water applied	(gal. of water applied ÷ sq. ft. irrigated area) ÷ 0.623
96.3 ÷ sq. ft. of irrigated area	gallon per minute precipitation rate (gpm)	inches per hour precipitation rate (in/hr)	sq. ft. of irrigated area ÷ 96.3
Plant Nutrients in Fertilizers and Soil Amendments (Dry Volume)			
2.29	elemental phosphorus (P)	P_2O_5	0.437
1.20	elemental potassium (K)	K_2O	0.830
1.39	elemental calcium (Ca)	CaO	0.715
1.66	elemental magnesium (Mg)	MgO	0.602
Pressure			
6,896	pounds per square inch (psi)	pascal (P)	0.000145
6.89	pound per square inch (psi)	kilopascal (kPa)	0.145
0.101	atmosphere (atm)	megapascal (MPa)	9.9
0.987	atmosphere	bar (b)	1.0
100	bar (b)	kilopascal	0.01
0.1	bar (b)	megapascal (MPa)	10
Electrical Conductivity (EC)			
1.0	decisiemens per meter (dS/m)	millimhos per centimeter (mmhos/cm)	1.0
10	siemen/meter	millimho/cm	0.1

Measurement Conversion Table, cont.

A to B	COLUMN A	COLUMN B	B to A
Energy			
1.055	British thermal unit (BTU)	kilojoule (kJ)	0.947
Metric System			
0.000001	micro- (millionth)	Base: 1 meter, 1 gram, 1 liter, 1 pascal, etc.	1,000,000
0.001	milli- (thousandth)		1,000
0.01	centi- (hundredth)		100
0.1	deci- (tenth)		10
10	deka- (ten)		0.1
100	hect(o)- (hundred)		0.01
1,000	kilo- (thousand)		0.001
1,000,000	mega- (million)		0.000001

Common Approximate Weight and Measure Equivalents for the Home Gardener

Weights	
Pounds per acre	**Quantity per 100 sq ft**
100	3½ oz
200	7½ oz
300	11 oz
400	14¾ oz
500	1 lb 2½ oz
600	1 lb 6 oz
700	1 lb 10 oz
800	1 lb 13 oz
900	2 lb 1 oz
1,000	2 lb 5 oz
2,000	4 lb 10 oz
Measures	
Liquids	**Quantity per 100 sq ft**
1 level tsp	⅙ fl oz
1 level tbsp	½ fl oz
1 level cup	8 fl oz
1 pt	1 lb
1 qt	2 lb
1 gal	8 lb

Glossary

abiotic. Nonliving physical and chemical components of the environment, including light, moisture, temperature, mechanical forces, and inorganic chemical compounds.

abscission. The dropping off of a leaf, fruit, or flower.

acid. See pH.

adventitious. Plant structures or organs, such as buds, shoots, or roots, produced in an abnormal position or that arise from other plant tissues.

aeration (soil). The process in which air in the spaces around soil particles is renewed.

aerobic. Occurring only in the presence of oxygen, or requiring oxygen.

aggregates (soil). Clusters of soil particles variable in shape, size, and degree of association, such as granules, clods, or prisms, that give a soil its structure.

agronomy. The science of the production of crops grown on large acreages, such as grains and forages.

air layering. A propagation technique in which plant parts are rooted while they remain attached to the parent plant.

alkaline. See pH.

alternate bearing. The bearing of heavier and then lighter crops of fruits in successive years.

alternate bud and leaves. The arrangement of buds or leaves singly at a node, usually on either side of the stem.

anaerobic. Occurring in the absence of oxygen or not requiring oxygen.

angiosperms. Flowering plants that produce their seeds within a fruit (ovary); the most advanced class of plants.

anion. A negatively charged ion. See ion.

annual. A plant in which the entire life cycle is normally completed in a single growing season.

anther. The upper portion of the stamen that produces pollen grains.

apical. Located at or pertaining to the apex or tip.

apical dominance. The influence of a terminal bud (apical bud) in suppressing the growth of lateral buds.

apical meristem. The tissues at the tip of roots and shoots where cells divide, giving rise to new growth.

apomictic seed. A seed developed from an unfertilized egg.

arthropods. Invertebrate organisms of the animal kingdom that include insects, spiders, and crustaceans; organisms characterized by an external skeleton and legs with movable segments or joints.

asexual (or vegetative) propagation. Production of a new plant by using a part of a parent plant, as opposed to sexual union; reproduction of a plant by any means other than seed.

assimilation. The conversion of food into cell walls and cell contents.

auxin. A generic term for a group of plant hormones that are active at low concentrations and that regulate plant growth and development, particularly cell division, cell elongation, adventitious root initiation, and bud dormancy.

available moisture. The amount of water in a soil that roots can absorb.

axil. The angle formed between a leaf and the stem on which it is attached.

bacteria. Microscopic, one-celled organisms that lack chlorophyll and may be parasites on plants or animals, causing disease; most are beneficial agents of fermentation and decay of organic matter.

banding. The placement of fertilizer in the soil close to a row of seed.

bare-root transplanting. A method of transplanting in which plants are dug from the ground with little or no soil left on the roots.

bark. The outermost tissue of a woody stem that usually includes portions of the phloem.

bark grafting. A technique in which the scion is inserted between the bark and the xylem of the stock.

basal. Pertaining to the base or lower part of an organ or plant part.

basal plate. The short, flattened stem at the base of a bulb.

biennial. A plant that normally requires two growing seasons to complete its life cycle. Only vegetative growth occurs the first year; flowering and fruiting occur the second year.

binomial system of nomenclature. The system in which the scientific name for any plant or other organism is composed of two Latin terms that designate genus and specific epithet; together, the genus and specific epithet create a species name.

biological pest control (biocontrol). The action of parasites, predators, pathogens, or competitors in reducing another organism's population density.

biotic. Pertaining to life or living.

bipinnate. Twice pinnate, as in a leaf blade.

blade. The usually broad, flattened part of a leaf.

blanching. To whiten (etiolate) a vegetable as it is growing by wrapping the stalk and leaves with paper or outer leaves, or by mounding soil around the portion to be whitened, such as celery.

blight. A disease causing sudden, severe leaf damage and/or general killing of stems or flowers.

blossom-end rot. A disorder of tomato fruit in which a sunken dry rot develops on the bottom; associated with calcium deficiency and water stress.

bolting. Premature flower and seed stalk formation, usually in biennial crops during their first year of growth.

botany. The scientific study of all facets of plant structure and behavior.

bract. A modified leaflike structure closely associated with a flower, sometimes petal-like.

bramble. Any plant of the genus Rubus, such as the blackberry and raspberry.

branch collar. The distinct enlarged portion of woody tissue formed at the base of a branch where it attaches to the trunk.

broadleaf. Plants possessing leaves that are thin, wide, and flattened.

bud. A protuberance on a plant stem containing an embryonic leafy or flowering shoot, or both.

budding. Grafting by inserting a single bud (scion) under the bark of the rootstock.

bulb. An underground storage structure composed of a short stem and overlapping, fleshy leaf bases surrounding a bud, as in onions and tulips.

bulk density (soil). The weight per unit of volume of nondisturbed soil that has been completely dried, commonly expressed as grams per cubic centimeter (g/cc); a means of characterizing the amount of macropores and compaction in soil.

calcareous (soil). A soil containing relatively high amounts of calcium carbonate, usually alkaline.

callus. Nonspecific tissue that forms a protective covering over a wounded plant surface.

calyx. The outer or lowest of the series of floral parts composed of the sepals. Usually green and leaflike, but may be colored like the petals.

cambium. A very thin zone or cylinder of meristematic cells, lateral in position, that gives rise to xylem and phloem; the tissue responsible for increases in stem and root diameter.

cane. The woody stem of small fruits such as grape or raspberry; sometimes applied to the stems of roses.

cane pruning. A system of pruning grapes in which all canes that previously fruited are removed, then a few 1-year-old canes are headed back and usually placed on a trellis.

canker. A localized area of diseased tissue on a stem, often sunken or swollen, surrounded by healthy tissue.

capillary forces. The absorptive force between a liquid (water) and the surrounding material (soil particles), coupled with the cohesive force in the liquid's surface (surface tension); forces that enable water to rise or be held in small spaces against the force of gravity.

capillary moisture. The water that is held by the soil against the force of gravity and that is available for plant absorption; the amount of water a soil will hold between wilting point and field capacity.

carbohydrate. An organic molecule composed of carbon, hydrogen, and oxygen, such as sugar, starch, or cellulose.

carbohydrate-nitrogen balance. The relative proportion of accumulated carbohydrates and nitrogen in stems and leaves of plants; important because it influences flower bud initiation and fruit set.

cation. A positively charged ion.

cation exchange. The interchange between a cation in solution and another cation on the surface of a colloidal or other surface-active material such as a particle of clay or organic matter in the soil.

cation exchange capacity. A measure of soil's ability to retain fertility (cationic forms of plant-essential elements); the sum of exchangeable cations absorbed by a soil, expressed in milliequivalents per 100 g of soil equivalent to the milligrams of H^+ that will combine with 100 g of dry soil.

cell. The structural unit composing the bodies of plants and animals; an organized unit of protoplasm, in plants usually surrounded by a cell wall.

cell membrane. The structure inside the cell wall that appears to have the function of regulating the flow of nutrients and other materials into and out of the cell.

cell wall. The membranous covering of a cell secreted by the cytoplasm in growing plants; consists largely of cellulose.

cellulose. A complex carbohydrate; the chief component of the cell wall in most plants.

central leader system. A system of tree training in which the trunk is encouraged to form a central axis with branches distributed laterally around it.

chelate. A metal ion bonded to an organic molecule from which it can be readily released, such as iron chelate or Sequestrene 138 Fe.

chilling requirement. The cumulative hours of temperature below 45°F required by many temperate woody plants in order to overcome bud dormancy and to retain vigor.

chlorophyll. The green plant pigment that absorbs light energy necessary to the process of photosynthesis.

chloroplast. A specialized body in the cell cytoplasm that contains chlorophyll.

chlorosis. Interveinal yellowing of foliage that results from a loss or deficiency of chlorophyll.

clay. Soil particles less than 0.002 mm in diameter; also, a textural class of soil.

clone. A group of genetically identical plants produced by asexual propagation from a single plant.

cold frame. A bottomless box with a removable clear top used to protect, propagate, or harden plants. No heating device is used.

cole crop. Any plant of the genus Brassica, of the crucifer family (e.g., cabbage, cauliflower, broccoli).

coleoptile. Sheathlike pointed structure covering the shoot of grass seedlings; commonly interpreted as the first leaf of the plant above the cotyledon.

companion planting. A form of intercropping in which specific kinds of plants are reported to mutually benefit from close association in the garden.

complete fertilizer. A fertilizer containing nitrogen, phosphorus, and potassium.

complete flower. Flower having all of the floral parts (stamens, pistil, petals, and sepals).

compound leaf. A leaf divided into two or more parts, or leaflets, all attached to the stem by a single petiole.

conifers. Plants that bear cone fruits, such as pines, cedars, spruces, and firs.

contact pesticide. A substance that kills a pest primarily by contacting its tissue rather than by internal absorption.

cool-season crop. Crop that thrives best or produces highest-quality crops in cool weather.

cordon. The main upper woody portion of a grape vine that is trained to a trellis and from which fruiting canes develop; also, a main branch of an espaliered fruit tree.

core. The innermost part of pome and certain other fruits that contains the seed; also, a receptacle tissue in certain plants, as in the raspberry.

corm. A short, thickened underground storage organ formed usually by enlargement of the base of the main plant stem.

corolla. The petals of a flower, collectively.

cortex. Unspecified outer tissues of the stem or root.

cotyledon. A seed leaf that is distinct from the characteristic leaves of a plant.

cross-pollination. The transfer of pollen from the anther of one plant to the stigma of another plant.

crown. The upper part of a tree or shrub, or the aboveground portion of a plant consisting of branches and leaves; also, the area where the stem and root join.

cucurbit. Any plant of the family Cucurbitaceae (e.g., cucumber, squash, watermelon).

cultivar (cultivated variety). A taxonomic group of plants, originally developed and now maintained under cultivation, that are significant in agriculture (horticulture) and are clearly distinguished by a characteristic that is retained when plants are propagated. In common horticultural usage, cultivar is synonymous with variety. Cultivars can be classified as those which are sexually reproduced and those which are asexually reproduced. In this Handbook, cultivar names are enclosed in quotation marks only when used as part of the scientific (Latin) name.

cuticle. A thin waxy or varnished-like layer that covers the epidermis of aboveground plant parts.

cutting. Any part that can be severed from a plant and used to regenerate a whole new plant, most commonly stem, root, leaf or bud cuttings.

cytoplasm. The living material in a cell (protoplasm), excluding the nucleus.

damping-off. Rotting of seedlings and cuttings caused by any of several fungi; a fungal attack near the soil line that causes cuttings or emerged seedlings to fall over and die.

day-neutral plant. A plant in which the flowering period or some other process is not influenced by length of daylight.

deciduous. Trees or shrubs that drop their leaves at the end of each growing season; contrasted with evergreen plants.

desiccant. A drying agent or substance that attracts or holds water and produces or maintains an extremely dry state within its vicinity.

desiccate. To dry out completely.

desiccation. The state of extreme or complete dryness or the process of becoming extremely dry.

determinate. A growth habit in which the main plant stem(s) (axis) terminate(s) in the development of a flower as in corn and some varieties of tomato.

dicot (dicotyledon). A flowering plant having two seed leaves, characteristic net-veined leaves, vascular tissues arranged in concentric rings, and flower parts in multiples of fours or fives.

diffusion. The dispersal of molecules from an area of greater concentration to an area of less concentration until the molecules are uniformly distributed.

dioecious. Literally, “two houses”; plants bearing staminate and pistillate flowers (or pollen and seed cones of conifers) on different individuals of the same species; species that produce separate male and female plants.

division (propagation). The technique of dividing a plant into two or more parts in which each part is a whole plant; often used with perennials.

dormancy. A period of inactivity or physiological rest, especially in bulbs, buds, seeds, and spores.

drip line. The imaginary vertical line extended from the outermost branch tips of a tree to the soil directly below.

drupe. A simple fleshy fruit in which the inner part of the ovary wall develops into a hard stony or woody endocarp, as in the peach.

dwarf. A plant that is much smaller when mature than others of its species, often achieved by grafting.

EC. Electrical conductivity of soil.

ectoparasite. A parasite that lives on the exterior of its host.

efficacious. Capable of producing the desired effect; effective.

electrical conductivity (of soil). An indirect means of measuring the salt concentration of a soil by gauging the ability of the soil solution to conduct an electrical current, which is a function of the amount of salt present. Abbreviated as EC and commonly expressed in units of millisiemens per meter (mS/m).

element. A substance in its simplest form that cannot be broken down further (e.g., carbon, oxygen, nitrogen).

embryo. A rudimentary plant formed within a seed.

endoparasite. A parasite that lives within its host, usually in its tissues or organs.

endosperm. The tissue in seeds that serves as a food reserve used by the embryo at germination; a large part of a mature seed may be endosperm tissue.

entomology. The scientific study of insects, including their anatomy, physiology, and behavior.

epidermis. The outermost layer of cells of the leaf and of young stems and roots.

espalier system. A method of tree training in which the tree is usually planted against a wall and the main branches trained in a plane parallel to the wall in a geometric design.

ethylene. A plant hormone that regulates ripening and flowering; ripening fruit and damaged plant tissues give off large quantities; used artificially for many purposes, including ripening and coloring certain fruit.

etiolate. To cause stems to become elongated, weak, and pale green in color, usually due to insufficient light.

evapotranspiration (ET). The loss of water from soil in a planted area by evaporation from the soil surface and plant transpiration.

evergreen. Plants that retain leaves or needles longer than one growing season so that some leaves are present throughout the year.

exocarp. Outermost layer of the fruit wall; often the skin of the fruit.

fasciation. Flattening and enlargement of a branch as if several stems were fused, often accompanied by curving. Believed to be caused by injury to the cells of the bud or by multiple terminal buds arranged in a single plane.

fastigiate. A narrow, upright growth habit.

fertilizer. A substance added to soil to provide plants with essential nutrient ions.

fertilization (botanical). The union of two gametes to form a zygote, as when a pollen grain germinates and unites with an ovule to form an embryo.

fertilizer analysis. A statement, usually on the label of a fertilizer container, of the percentages by weights of nitrogen, phosphoric acid, and potash contained in the material.

fertilizer formula. The quantity and grade of crude stock materials used in making a fertilizer mixture.

fibrous rooted. A root system in which the roots branch near the crown and become finely divided.

field capacity. The amount of water a soil can hold against gravity. See capillary moisture.

filament. The stalk of the stamen supporting the anther.

flocculate. To aggregate individual particles into small clusters; the aggregation of soil particles into variously shaped small groups (crumbs, plates, clods, prisms) that create structure.

floret. An individual flower that is a part of a flower head.

floricane. In raspberries, the two-year old stems (canes) that produce flowers and fruit.

flower. The reproductive structure of the angiosperms.

foot-candle. The density of light striking the inner surface of a sphere with all the surface area being 1 foot away from a 1-candle-power source.

frass. The solid fecal material produced by insect larvae.

fruit. In botany, the matured ovary of a flowering plant containing seed; in horticulture, a fleshy, ripened ovary of a plant eaten for its dessert quality.

fruit set. The inhibition of a fruit to drop after a flower is pollinated.

full-slip. In harvesting of melons, the point of maturity when there is easy separation of the fruit from the vine.

fungi. A lower order of plant organisms, excluding bacteria, that have no chlorophyll or vascular system. Their vegetative body consists of threadlike hyphae, and they often develop spore-producing structures. Some cause diseases of horticultural crops; others (mushrooms) are grown as food; most are beneficial saprophytes.

fungicide. A substance that kills or inhibits fungi.

furrow. A depression in the ground surface dug along a prescribed line for planting seed, irrigating, controlling surface water, or reducing soil loss.

gamete. A reproductive body capable of fusion with another; the sperm from the pollen grain and the egg from the ovule.

gametophyte. Typically a haploid, gamete-producing plant derived from a spore, as in ferns; in higher plants, the sperm and egg and the haploid cells from which they develop.

gene. A unit of inheritance, located on chromosomes, composed of DNA.

genus. A group of closely related plants that is clearly differentiated from other groups.

germination. The beginning or resumption of growth of a seed, embryo, or spore, including pollen grain on a stigma; the sprouting of a seed.

germ plasm (germplasm). Hereditary materials (chromosomes, genes, and any other self-propagating particles); the total genetic resources available in the entire population of a crop or species.

gibberellins (gibberellic acid, GA). A group of plant hormones regulating stem elongation, seed germination, and other growth.

girdling. Constricting or removing the outer tissues around a stem as deep or deeper than the cambium, which disrupts the flow of carbohydrates through the phloem.

grafting. The process of inserting a part of one plant into or onto another in a way that the two will unite and continue growth as a single unit.

granule (soil). Rounded or sub-angular, relatively small, dense soil aggregate.

gravitational water. Water that moves through soil under the force of gravity.

green manure. A crop plowed under when green for its beneficial effect on soil structure and fertility.

gray water. Water discharged after household use, including water used for clothes washing, dish washing, and bathing, but excluding water from toilets.

guard cells. Specialized crescent-shaped epidermal cells that surround a stomate and control its aperture.

gymnosperms. Seed-producing, nonflowering plants having ovules borne on open cones or scales rather than an enclosed ovary, such as the needle evergreens, pine, fir, and cedar.

half-slip. In harvesting of melons, a stage of maturity in which, as the fruit is pulled from the vine, only a portion of the stem separates easily from the base of the fruit.

haploid. Having the gametic number of chromosomes, or half the number characteristic of somatic (nonreproductive) cells.

hardening. Treating plants to make them more resistant to adverse environmental conditions, usually by exposing them gradually to increased light, temperature changes, and drought.

hardening-off. See hardening.

hardpan. A subsurface layer of compacted or cemented soil.

hardscape. The portions of a landscape or garden area that are paved.

hardwood stem cutting. A mature shoot of the last season's growth that is removed from the plant after the leaves have fallen to be used in propagating new plants.

heading back. Pruning the end of a branch or stem by cutting it back to a bud or side branch.

heartwood. Nonliving, often darker-colored wood toward the center of a tree trunk that is surrounded by sapwood.

heirloom variety. A crop variety or cultivar documented to have been in cultivation for 50 years or longer and is open-pollinated in origin.

hedgerow. A widened row sometimes used for bramble fruits in which new canes are permitted to grow between the original plants in the row.

herbaceous. A plant or portion of a plant that lacks pronounced woody structure or tissue.

herbicide. A substance that kills plants.

horizon (soil). A distinctive soil layer that has well-defined characteristics.

hormone. An organic substance that, in minute quantities, is usually produced in one part of an organism and transported to another, where it affects or regulates growth and development of tissues.

horticulture. The art and science of cultivating high-value, often highly perishable crops (sometimes called "garden crops"), including fruits, vegetables, flowers, and landscape trees and shrubs.

hotbed. Small enclosed garden bed, having a transparent covering, in which the soil is heated.

humus. Organic matter in a highly decayed state, rich in plant nutrient ions, and very retentive of water when added to soil.

hybrid. Progeny of a cross between two individuals differing in one or more genes (characteristics). In horticulture, the cultivar resulting from a controlled or manipulated cross of two genetically diverse parents. An F1 hybrid is the first generation of offspring from a cross of two distinct parents.

hypha (pl., hyphae). A threadlike structure composed of one or more tubular cells that make(s) up the body of a fungus.

hypocotyl. Part of the stem of an embryo or seedling below the cotyledons and above the radicle or embryonic root.

imperfect flower. Flower containing either stamens or pistil but not both.

incomplete flower. Flower lacking one or more of the floral organs (sepals, petals, stamens, or pistil).

indeterminate. A growth habit in which the main plant stem(s) (axis) remain(s) vegetative and in which flowers form on axillary buds; growth and flowering can continue indefinitely through the plant's life cycle as in cucumber and some tomato varieties.

infection. The establishment of the pathogen in the host.

inflorescence. The arrangement of a flower or flowers on an axis; a flower cluster.

inoculum. A pathogen or its parts (spores, mycelium, etc.) that can incite infection.

inorganic. Not composed of or derived from plant or animal materials; also, a compound that does not contain carbon.

insecticide. A substance that kills insects.

instar. The period between molts in the larvae of insects.

integrated pest management (IPM). A strategy that centers on long-term prevention or suppression of pest problems through a combination of techniques such as resistant varieties, biological control, cultural practices, habitat modification, and the use of pesticides when careful field monitoring indicates they are needed according to treatment thresholds.

intercropping. Growing two or more crops in the same planting area simultaneously, as in planting squash in between rows of corn.

internode. The portion of the stem between any two nodes.

ion. An atom or group of atoms that carries a negative (anion) or positive (cation) charge, formed by the breakup (disassociation) of molecules as happens when certain molecules or compounds are dissolved in water.

IPM. See integrated pest management.

iron chlorosis. A yellowing or loss of green color in leaf tissue, commonly between the veins, due to an insufficient concentration of iron in the plant.

June drop. The dropping of immature tree fruits during the early summer; believed to be caused most frequently by embryo abortion or an extremely large crop load.

juvenility. The early period in a plant's life cycle characterized by vigorous vegetative growth, sometimes distinctive in form from mature growth, and no flower production.

lateral bud. A bud attached to the side of a stem.

layering. A method of vegetatively propagating woody plants by covering portions of their stems or branches with moist soil or sphagnum moss so that adventitious root will form. The branch is then removed from the parent plant. See air layering.

leaching. Removing salts, ions, or other soluble substances from soil by abundant irrigation combined with drainage; also, the movement of soluble materials downward with percolating water.

leaf. A plant organ typically attached to a stem, varying in size and shape but usually flattened or needlelike and green in color that is concerned primarily with the manufacture of carbohydrates by photosynthesis.

leaflet. A segment of a compound leaf.

legume. A plant of the family Leguminosae, such as peas and beans; characterized by a fruit pod that opens along two sutures when ripe.

lenticel. Opening through the bark or outer covering of fruits and stems (and sometimes other organs), that permits exchange of gases from the inner tissues with the surrounding air.

lignification. The process in which plant cells become woody by conversion of certain constituents of the cell wall into lignin; generally considered to include the hardening, strengthening, and cementing of the cell walls in the formation of wood.

loam. A soil that contains 7 to 27% clay, 28 to 50% silt, and less than 52% sand, which has an ideal structure for cultivation and plant growth.

long-day plant. A plant in which the flowering period or other process is regulated by daily exposure to light longer than a certain minimum number of hours, usually more than 12 hours.

macronutrient. Plant-essential elements required in relatively large amounts by plants.

macropores. The relatively large spaces among soil aggregates from which water readily drains and in which air resides.

massive soil structure. A type of soil structure in which no aggregates naturally form, and when disturbed by digging, large clods are created, as in heavy clay, and compacted soils or soil particles remain totally separate, as in beach sand; a soil without structure.

meristem. A region in which new cells and tissue arise, resulting in growth.

metabolism. The total of the chemical processes in a plant or other organism.

microclimate. Local variations from the general or regional climate resulting from slight differences in elevation, direction of slope exposure, soil, density of vegetation, etc.

micronutrient. Plant-essential element required by plants in very small amounts.

micropores. The relatively small spaces among soil aggregates that hold plant-available water by capillary force.

mineralization. The conversion of an element from an organic compound, in which it is unavailable to plants, to an ionic form in which it is available to plants.

miticide. A substance that kills mites.

mixed bud. A bud that produces both leaves and flowers.

modified central leader system. A training system extensively used with apples and pears in which the central leader is headed back slightly but not completely removed.

monocot (monocotyledon). A flowering plant having one seed leaf, parallel-veined characteristic leaves, scattered vascular bundles, and flower parts in multiples of threes.

monoecious. Bearing both staminate (male) and pistillate (female) flowers (or pollen and seed cones of conifers) at different locations on the same plant; common in plants of the Araceae and Cucurbitaceae families.

mulch. Any materials placed on the soil to conserve soil moisture, moderate soil temperature, prevent soil erosion, or prevent weed growth.

mycelium. A mass of hyphae of a fungus.

necrosis. The death of a cell, tissue, or organ while the remainder of the plant is still living.

nematicide. A substance that kills nematodes.

nematode. Any of the round, cylindrical, unsegmented worms of the phylum Nematoda; some cause plant diseases.

node. A point on the stem where leaves are attached and buds arise in the axils of the leaves.

nucleus. A specialized body within a cell that contains genetic information and is associated with the control of essential processes within the cell.

obligate. An organism that can develop and survive in only one type of environment; as in obligate parasite, which is any parasite that cannot exist independently of its living host.

offset. A short, prostrate offshoot or branch growing from the crown of a plant and having a fleshy, scaly bud or a rosette of leaves located terminally. Offsets often form roots and are used to vegetatively propagate some plants.

offshoot. A lateral shoot that rises from the main stem of a plant; often used for vegetative propagation of some plants, e.g., date palms.

open center system. See vase system.

open pollination. Pollination that occurs by natural mechanisms among individual plants with no control so that the male (pollen source) is unknown and sometimes results in wide variation in genetic traits in the offspring. In crops that naturally self-pollinate and whose traits breed true, open-pollinated offspring are nearly identical with very rare off types.

opposite buds and leaves. Arrangement in which buds and leaves occur in pairs at a node, directly across the stem from each other.

organic. Composed of or derived from plant or animal material; also, a compound that contains carbon.

ovary. The swollen basal portion of a pistil; the flower part containing the ovule(s) or seed.

ovule. Part of the ovary containing one female gametophyte (egg). Following fertilization, the ovule develops into the seed.

palisade layer. A layer of tightly spaced, elongated cells lying under the upper epidermis of leaves. Photosynthesis is most active in these cells.

palmate. Having the general shape of human hand with the fingers extended.

parasite. An organism that lives in or on another organism (host) and obtains its nourishment from the host without contributing to its survival.

parthenocarpic fruit. Fruit produced without fertilization.

ped. An individual, natural soil aggregate such as crumb, prism, or granule.

perennial. A woody or herbaceous plant that lives from year to year and does not die after flowering once.

perfect flower. A flower containing both stamens and pistil; a bisexual flower.

perlite. White and very porous volcanic mineral that is sometimes used as a medium for rooting cuttings or as a soil amendment.

petiole. The thin stalk that attaches a leaf to the stem.

pH. The negative logarithm of the hydrogen-ion concentration of a solution; a notation to express the alkalinity or acidity of a solution, as in the solution formed when water is present in soil, on a scale from 0.0 to 14.0. A pH of 7.0 is neutral, values less than 7.0 are acid, and values greater than 7.0 are alkaline.

pheromone. A substance that is produced and discharged by one organism and that induces a physiological response in another, such as the sexual attractants of insects.

phloem. Vascular tissue that conducts synthesized carbohydrates in vascular plants.

photoperiod. The length of light in a 24-hour day.

photoperiodism. The response of some plants to the relative lengths of day and night, expressed as formation of flowers, tubers, etc.

photosynthesis. The production of carbohydrate (sugar) from carbon dioxide and water in the presence of chlorophyll, using light energy and releasing oxygen.

phytotoxic. Harmful or poisonous to a plant or portions of a plant; substances that are poisonous to all or certain plants.

pinnate. The pattern of arrangement of dicot leaf veins, leaflets of compound leaves, lobes, etc., that resembles the structure of a feather in that they are arranged along the sides of a central axis (e.g., a major leaf vein, major petiole, etc.).

pistil. The central and female part of a flower consisting of the stigma, style, and ovary, and having one or more compartments (carpels) that bear the ovule(s).

plumule. The bud of an embryonic plant.

pollen (grain). Tiny, grainlike structures in the anther of a stamen containing sperm nuclei that represent the male gamete in seed plants.

pollen tube. The tube formed in the style following germination of the pollen grain.

pollination. Transfer of pollen from the anther to the stigma of the same or another flower.

pome. A fleshy fruit with a leathery core as produced by apple, pear, and quince.

porosity (soil). The degree to which a soil is permeated with open spaces, cavities, or pores; expressed as a percentage of the total volume of a quantity of undisturbed soil.

postemergent herbicide. An herbicide that is applied after weed seeds emerge or geminate.

pot herb. Greens; any plant yielding foliage that is edible when cooked, such as spinach, kale, chard, mustard.

predator. Any animal, including insects, that preys upon and devours other animals. Distinguished from a parasite, which lives on only one host at a time and usually does not destroy the host.

preemergent herbicide. An herbicide that is applied before weed seeds emerge or germinate.

primocanes. One-year old (or less) stems in blackberries and raspberries that do not bear fruit.

prismatic (soil structure). A type of soil structure in which the aggregates that naturally form are relatively large and angular, resembling a prism.

propagate. To generate or to multiply by sexual or asexual means.

propagule. A newly propagated plant.

protoplasm. The living material of and in a cell.

pupa. In insects with complete metamorphosis, the inactive stage between the larva and adult, usually enclosed in a protective structure.

quiescent. Dormant or inactive.

radicle. The basal end of an embryonic stem that grows into the primary root.

receptacle. A part of the axis of a flower stalk that supports or surrounds the floral parts.

reproductive. Growth, tissues, or processes concerned with the growth and development of flowers and fruits as opposed to leaves stems, and roots; sexual.

respiration. The controlled process in cells in which carbohydrate is biologically broken down (oxidized) and energy is released.

rhizome. A specialized stem, usually horizontal in position at or just below the soil surface, distinguished from a root by the presence of nodes and internodes and sometimes buds.

root ball. In container-grown and dug plants, the mass of roots attached to the plant.

root cap. The protective, thimble-shaped mass of cells over the root rip.

rootstock. In grafted plants, the rooted plant or plant part to which a scion is attached.

runner. A thin, specialized stem that grows along the soil surface and produces adventitious roots and shoots.

russeting. Brownish, roughened areas on the skins of fruits, tubers of potatoes, etc., resulting from abnormal production of cork tissue. May be caused by disease, insects, or injury, or may be a natural varietal characteristic.

saline soil. A soil containing sufficient soluble salts to impair plant growth and development.

salinity (of soil). See electrical conductivity.

sand. A group of textural classes of soil in which the particles are finer than gravel but coarser than silt, ranging in size from 2.00 to 0.5 mm in diameter. Any soil class that contains 85% or more sand and not more than 10% clay.

sap. The liquid contents of a cell or the liquid flowing through xylem or phloem.

saprophyte. An organism that obtains its food from the remains of dead plants or animals.

sapwood. The outer wood of a stem or tree trunk, usually light in color and physiologically very active.

scaffold (branches). The main branch(es) of a tree.

scarification. The abrasion, scratching, or modification of a seed's surface to increase water absorption and break dormancy.

scion. A branch, bud, or shoot removed from one plant and grafted onto another plant (the stock or rootstock).

scoring. A type of phloem disruption that consists of running a knife blade around the stem to make a narrow cut through the phloem.

seed. Structure that is formed by seed plants following fertilization and that contains an embryonic plant and usually a food supply and protective covering; a fertilized ovule.

seed coat. The outer covering of a seed.

self-compatible (self-fruitful). Able to produce normal fruit and seed with self-pollination; sets and matures fruit without pollen from another cultivar.

self-incompatible (self-unfruitful). Unable to produce fruit and seed when self-pollinated; requires cross-pollination from another cultivar.

self-pollination. Transfer of pollen from the anther to the stigma of the same flower or of another flower on the same plant or within a cultivar.

senescence. The stage in the life of a plant or plant part when its rate of metabolic activity declines prior to death.

sepal. One segment of the calyx.

set. A small propagative part (bulb, shoot, tuber, etc.) suitable for setting out or planting.

sexual propagation (seed propagation). Propagation that uses the fusion of male and female gametes to develop a new individual plant.

sexual reproduction. See sexual propagation.

shoot. The upper part of a plant consisting of stems, leaves and flowers; a young growing branch or twig.

short-day plant. A plant in which the flowering period or some other process is regulated by daily exposure to light shorter than a certain maximum number of hours, usually less than 12 hours.

sidedressing. Applying fertilizer to the soil at the side of a plant row, usually after the crop has started to grow.

silt. Small, mineral soil particles ranging from 0.05 to 0.002 mm in diameter; also, a soil textural class of soils that contains 80% or more silt and less than 12% clay.

slip. A cutting from a plant, usually softwood or herbaceous, used for propagation or grafting.

slip (melon harvesting). See full-slip and half-slip.

STM. See soil moisture tension.

sodic soil. A soil that contains sufficient sodium to adversely affect its physical properties and water infiltration; a soil with an exchangeable sodium percentage greater than or equal to 15%.

soil. The natural medium on the surface of the earth composed of minerals, organic matter, water, air, and various organisms, in which plants typically grow.

soil amendment. A substance added to soil to alter one or more of its physical or chemical properties.

soil horizon (profile**)**. A layer of soil with well-defined physical and chemical characteristics produced through the soil-formation processes.

soil moisture tension (SMT). The amount of force under which a given quantity of water is held by a soil.

soil structure. The degree that soil particles (sand, silt, clay) naturally arrange into aggregates that vary in form and size, such as granular, platy, massive, and single-grained.

soil texture. The relative proportions of sand, silt, and clay in a soil expressed as a percent by weight; the coarseness or fineness of a soil.

species. A group of closely related individuals that are self-perpetuating and usually inter-cross; the basic unit of the binomial system of naming organisms, as in Liquidambar styraciflua (American sweetgum), which consists of a genus name and its specific epithet. Abbreviated as sp. (sing.) or spp. (pl.).

specific epithet. In the botanical or binomial system of identifying organisms, the descriptive term that modifies the genus in a specific name, often mistakenly called species; e.g. *Liquidambar styraciflua* is the species name, Liquidambar is the genus and styraciflua is the specific epithet.

sperm. A mature male germ cell.

spore. A minute reproductive body or cell produced by lower plants.

spur. A short, stubby lateral stem primarily bearing flowers, as in some fruit trees.

spur pruning. A system of pruning grapes in which dormant canes are headed back to create short stubs bearing two or three buds.

spur-type tree. A fruit tree (primarily apple and cherry) that has shortened internodes and a greater number of spurs; about two-thirds the height of standard non-spur-type trees.

stamen. The male part of the flower producing the pollen, usually composed of anther and filament.

staminate. A flower that has stamens but no pistil and hence is imperfect; a plant bearing only male flowers.

stem. An axis of a plant usually bearing leaves with buds in the axils. It may be above or below ground, and the leaves may be functional or specialized.

stem cutting. Any part of a stem used for plant propagation by severing it from the parent plant.

stigma. The apex of the pistil that receives pollen.

stock. See rootstock.

stolon. A horizontal or trailing stem that gives rise to new shoots; a runner.

stomate (stoma) (pl., stomata). The opening or pore, mainly in leaves, through which gases are exchanged and water vapor is lost; controlled by guard cells.

stratification. A method of storing seeds or other reproductive structures at a temperature from 35° to 45°F in alternate layers with (or mixed in with) moist sand, peat moss, or other medium, as a means of overcoming dormancy.

style. The part of the pistil that connects the ovary and stigma, through which the pollen tube grows to the ovule.

subspecies. A group of individuals within a species, distinguished by certain common geographical or varietal characters. Abbreviated as ssp.

subtropical crop. A crop that will survive very short periods of freezing temperatures but will not survive in areas with a cold winter climate.

succession planting. Growing two or more crops, one after the other, on the same land in one growing season.

sucker. A rapidly-growing, upright secondary vegetative shoot that develops from the root, crown, or stem of a plant.

taproot. A stout, tapering main root from which arise smaller lateral roots.

temperate zone crop. A crop able to adapt so that it survives temperatures considerably below the freezing point.

terminal bud. A bud that develops at the end of a stem or shoot.

thatch. The layer of dry, dead plant material and organic matter at the soil surface, common in turfgrass.

thinning. Removal of an entire shoot or branch.

tilth. The physical condition of the soil in relation to its ability to support plant growth.

tissue. A group of organized plant cells that perform a specific function.

topdressing. A material, such as sand or fine-textured organic matter, applied thinly to the soil or crop surface as a fertilizer, soil conditioner, or to reduce thatch.

topping. The cutting off of the main leader of a tree.

training. Directing the growth of a plant to a desired shape by pruning while young or fastening the stem and branches to a support.

translocation. The movement of a substance such as water, carbohydrates, or a pesticide from one part of a plant to another.

transpiration. The loss of water from plant tissues in the form of vapor, mainly through stomata.

tropical crop. A crop that originated in tropical areas and is usually subject to cold injury at temperatures near the freezing point.

tuber. An enlarged, fleshy, underground stem bearing buds; usually a storage organ.

tuberous root. An enlarged root that tapers toward both ends, as in dahlia and sweet potato; usually a storage organ.

unavailable water. Water held by the soil at and below the wilting point; water held by soil so tightly that plants cannot absorb it.

vascular tissue. The tissue consisting of xylem and/or phloem that is responsible for transporting water, carbohydrates, and/or the associated soluble materials through higher plants.

vacuole. The large cavity within the protoplasm of a cell containing a solution of sugars, salts, etc.

variety. In the botanical or binomial system of identifying organisms, a naturally occurring population of individuals constituting a subdivision of a species. Although technically different, variety and cultivar are commonly used synonymously.

vascular bundle. A strandlike portion of the vascular tissue of a plant, composed of xylem and phloem, typical in monocots.

vascular cambium. See cambium.

vase (open-center) system. A system of training in which the central leader is cut off 18 to 30 inches from the ground, and three to five side branches become the scaffolds and spread to form the framework of the tree.

vector. An organism, usually an animal, that can transmit a pathogen.

vegetative. Growth, tissues, or processes concerned with the growth and maintenance of the plant body; asexual; concerned with leaves, stems, roots as opposed to flowers and fruits.

vegetative propagation. See asexual propagation.

vein. The vascular bundle forming a part of the framework of the conducting and supporting tissue of a leaf or other plant organ.

vernalization. The inducement or promotion of flowering by exposure to low temperature, as in some bulbs and biennial plants.

virulence. A strong capacity to produce disease.

volatilization. Evaporation of a substance under normal temperature and pressure ranges.

warm-season crop. A crop, usually of tropical origin, that goes dormant or is injured as soon as temperatures drop slightly below freezing; crops that grow best or produce highest quality produce during the warmest season(s).

water sprout. See sucker.

weed. Any plant growing out of place; a plant growing where it is unwanted or interferes with more desirable plants.

whorled. A pattern of arrangement with three or more buds, leaves, or branches, usually at a single node, each on a different plane.

wilted. Lacking turgidity; drooping or shriveling of plant tissue usually due to a deficiency of water.

wilting point. The stage in soil moisture depletion where a plant is unable to take additional moisture from the soil and, as a consequence, becomes wilted.

WIN (water insoluble nitrogen). In fertilizer, a source of nitrogen that is not readily soluble in water and not subject to immediate leaching.

xylem. Vascular tissue primarily responsible for transporting water and mineral nutrients from the roots to the shoots; the primary component of wood in trees.

zygote. A single cell resulting from the fertilization of an egg by a sperm and capable of developing into an embryo.

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